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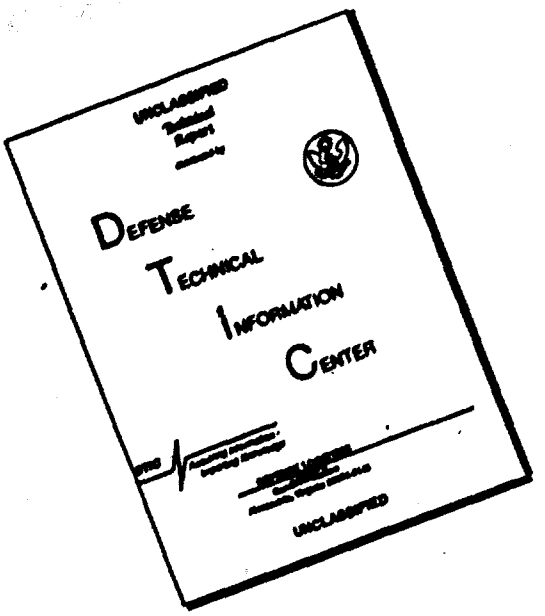

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Technical Note N-195
5 August 1954

technical note

TESTS OF BUSHIPS ANCHORS IN MUD AND SAND BOTTOMS

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Figure 1. Mud Bottom Test Site in San Francisco Bay.

INTRODUCTION

These anchor tests were conducted by the U. S. Navy, Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California at the request of the Bureau of Ships. The tests were made in the mud bottom of San Francisco Bay at the San Francisco Naval Shipyard, Hunters Point, California, and in a sand bottom at Port Hueneme, California.

The purpose of the tests was to provide comparative holding power data of several lightweight and Navy stockless anchors presently being utilized by the Bureau of Ships.

This report contains a description of the tests together with the results and observations.

ANCHOR TEST APPARATUS

The test apparatus for mud bottom tests consisted of two 5 x 12 pontoon barges, used to carry the test equipment, and a 5 x 12 pontoon warping tug, used to drop and retrieve the anchors. The test equipment was composed of a 400,000-lb. capacity electric dynamometer to measure the holding power of the anchors and a model BU-140 Skagit winch with a six-part line for dragging the anchors. The winch was spooled with 2,500-ft of 1-3/8 in. diameter wire rope, and the wire rope was reeved through sheaves mounted on the two barges to form the six-part line. One of the 5 x 12 pontoon barges was anchored with two 30,000-lb. Navy Stockless anchors and the other barge was attached to the test anchor with suitable lengths of anchor chain. Figure 1 shows a general view of the barges at Hunters Point during the tests. In this view the test anchor is located beneath the buoy between the two furthest barges and the buoy in the right foreground locates one of the 30,000-lb. stockless anchors used to hold the barges in position.

The vertical force required to break the test anchor loose from the mud bottom at the end of each test pull was measured by means of a strain gage mounted on the warping tug winch line. See Figure 2. Depth of water was approximately 30-ft at the test site.

The test apparatus for sand bottom tests consisted of a 20-ft gage railway, 300-ft in length, the open end of which is 100-ft above mean low tide; a 20,000-lb. gross weight, traveling instrument car; and a winch mounted on a stationary platform at the inshore end. See Figure 3. The instrument car was fabricated to simulate the movement of a ship dragging its anchor and to carry a 400,000-lb. capacity electric dynamometer, Figure 4, to measure the holding power of the anchors. A portable, dry-cell battery powered, indicator was used to record the holding power.

SOIL SAMPLES

Samples of the mud were taken in the path of the test pulls down to a depth of 70-ft. A mechanical analysis was conducted by the Soils Division of the Laboratory. See Table I. A soil shear strength and water content analysis of the bay mud are shown in Table II.

A mechanical analysis of the sand at the Port Hueneme test site showed 9% per cent sand particles, 92 per cent of which was finer than 0.6 mm, the remainder being less than 2.0 mm in size.

TEST ANCHORS

The test anchors consisted of a 2,000-, 3,000-, 4,000- and 10,000-lb. Lightweight; a 4,000-, 8,000-, and 17,000-lb. Navy stockless; and a 2,110-lb. British Mulock. The Mulock anchor is equipped with a 12-in. long stabilizer fabricated from 2-in. steel round stock. See Figures 5, 6, 7, 8, 9, and 10. In order to improve the holding power of the LWT anchors, the 2,000-, 3,000-, and 4,000-lb. LWT anchors were modified as per Bulkips instructions to a full fluke shape by welding fluke extension plates to the base of the conventional fluke and these anchors were retested in both mud and sand. See Figure 11. Two new design Baldt anchors, 3,170-lb. and 3,650-lb., and a 3,060-lb. Croseck anchor were also tested. See Figures 12, 13, and 14.

TEST RESULTS, MUD BOTTOM

The 2,000-, 3,000-, and 4,000-lb. Lightweight and 4,000-, and 8,000-lb. Navy stockless anchors were pulled at chain angles of 0-, 6-, and 12-degrees. The proper chain lengths for 0-, 6-, and 12-degree chain angles were obtained by the formula presented in the U. S. Navy Technical Publication entitled "Mooring Guide" NavDocks TP-pw-2. The remainder of the anchors were pulled at a zero degree chain angle only. Six tests were conducted with each anchor at each chain angle. Results of these tests are contained in Table III. Figures 15 through 38 are graphs of the six test pulls on each anchor showing holding power versus anchor travel. Figures 35, 36, and 35 are the graphs of the 2,000-lb., 3,000-lb., and 4,000-lb. LWT anchors with fluke extension plates. The holding power breakout force, and chain angles for each anchor are shown in the table.

Initial tests on the 3,170-lb. new design Baldt anchor showed a holding power to anchor weight ratio of 2.36 to 1 at a zero degree chain angle. This low ratio, for an anchor of this design, indicated that the flukes were not opening properly so the chain length was shortened, to lift the shank slightly thus opening the flukes, and the anchor was retested. Holding power ratio was increased to 6.62 to 1.

[illegible] anchor chain were [illegible] for [illegible] the resistance of the chain dragging through the sand bottom. The average holding power of [illegible]-ft of [illegible] in. anchor chain was [illegible] kips and for 180-ft of [illegible] in. anchor chain, [illegible] kips.

TEST RESULTS, CAST BOTTOM

Six tests were conducted with each anchor at zero degree chain angle only. Results of these tests are contained in Table IV. Figures [illegible] through [illegible] are graphs of the six test pulls on each anchor showing holding power versus anchor travel.

Test pulls of the anchor chain alone showed an average holding power of 23.3 kips for 210-ft of [illegible]-in. anchor chain and 3.0 kips for 90-ft of 1-1/2 in. anchor chain.

The tests conducted in the beach sand above the water line indicate a higher holding power than the same anchors will produce in sand under water. This is due to the different in-place densities of the sands above and below water. The sand being less dense under water[1]. The indicated holding powers on the beach are approximately 33 per cent higher than under water.

OBSERVATIONS

The holding power of individual anchors may be low when pulled in a mud or sand bottom due to the failure of the flukes to open in mud or because the flukes open too wide in sand. The flukes fail to open in mud bottom due to insufficient area in the tripping plates in relation to the large area in the flukes. In the initial setting of the anchor, the flukes are normally parallel to the bottom and are supported underneath by the mud. In this position there is nothing of sufficient resistance to cause them to drop down and dig into the mud.

In sand bottom the anchors which have a large fluke opening, approximately 89-degrees, will open up but will not bury into the sand due to the incorrect angle of pull on shank and flukes. This condition has been observed while testing on the beach where the anchors are visible and is also indicated in the comparison of the holding powers when the chain angle is changed from zero degrees to six and twelve degrees in mud bottom. For the Lightweight anchors, the holding power at 12-degree chain angle was actually higher in two instances than at 6-degree chain angle. See Table III. For the Stockless anchors, the increase of holding power from zero degree chain angle to 6-, and 12-degrees is only slight after dragging 50-ft and becomes greater as the anchor is dragged further. The larger chain angle

1. NAVDOCKLAB Technical Memorandum M-266, Test of Anchors for Moorings and Ground Tackle Design by R. D. Towne, 10 June 1953, p. 13 and BUDOCKS Soils Laboratory Report, Sand Samples, Anchor Tests, Steel & Concrete-Stee. Anchors, by L. A. Palmer, 5 January 1950.

apparently tends to lift the anchor shank and thereby open the flukes and permit them to start digging into the mud. This was shown in the tests on the new design 3,170-lb. Baldt anchor when the chain length was shortened and the holding power ratio to anchor weight was increased from 2.45 to 1 up to 6.6 to 1.

Stocklees anchors have been tested in mud bottom with the flukes fixed at their maximum fluke opening and the holding power to weight ratio averaged 4.2 to 1, compared to 2.49 to 1 for the same anchors without the flukes fixed in an open position, indicating further the inability of the anchor flukes to assume an open position. Anchors utilized in these particular tests were a 6,000-, 10,000-, and 20,000-lb Navy stocklees.

The Mulock anchor stabilizer is of insufficient length, 12-in., to prevent rotation, thereby reducing its maximum holding power. The anchor started to penetrate the sand bottom rapidly but would rotate 180-degrees and pull out in a short distance.

The new design Baldt anchors were designed primarily for mud bottom and due to the large fluke opening, 50-degrees, would not penetrate the sand bottom properly and resulted in a lower holding power than would normally be expected from an anchor of this design.

Previous tests[1] made in sand bottom have shown that a fluke angle of 35-degrees produces the maximum holding power for the anchors in sand bottom and preliminary tests in mud have indicated that a larger fluke angle of approximately 50 to 70 degrees will produce the maximum holding power. These fluke angle tests in mud bottom are being continued.

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1. (See page 3.)

TABLE I

MECHANICAL ANALYSIS
Hunters Point Mud

Depth - ft	Very Fine Sand .05 - .07 mm	Silt* .005 - .05 mm	Clay* .001 -.005 mm
C-1	40	30	30
10-11	2	48	50
19-20	--	40	60

* Per cent by weight

TABLE II

SOIL SHEAR STRENGTH AND WATER CONTENT *
Hunters Point Mud

Depth - ft	Unconfined Compressive Strength - psf	Shear - psf (1/2 U.C.S.)	Cohesion - psf	Natural Water Content - %
12	195	97.5	97	8[illegible]
22	325	16[illegible]	162	7[illegible]
32.5	504	252.0	252	75
42.5	230	115.0	115	79.[illegible]
52.5	80	40.0	40	72.0

* From NAVCEREL AB Technical Memorandum M-049, Grouting in Soft Soils by Philip P. Brown dated 21 May 1953.

OFFIC[illegible]

TABLE III

Holding Power Data of Steel Anchors tested in Mud Bottom at Hunters Point

Anchor	Wt-lb	Fluke Angle	Average Holding Power length of drag 50-ft	100-ft	150-ft	Minimum Holding Power length of drag 50-ft	100-ft	150-ft	Chain Angle Degrees	Average Break-out Force-lb
Lightweight	2000	29	7500	7900	8800	5000	5700	6500	0	5300
"	2000		5400	6700	7400	4200	5300	5500	6	3500
"	2000		5800	6800	7600	4800	5700	5700	12	3300
Lightweight	3000	30	11700	12600	13000	8600	8600	8600	0	8500
"	3000		10000	12600	12900	7700	8600	11500	6	7500
"	3000		8400	10200	11100	4800	6700	7700	12	8300
Lightweight	4000	30	11400	13200	15700	7700	9600	11500	0	7400
"	4000		8700	13500	13800	5700	9600	9600	6	6200
"	4000		9500	12200	14300	6700	8600	9600	12	9700
Lightweight	10000	30	18800	20900	21100	13100	17700	16700	0	12700
Navy Stockless	4000	45	10800	12900	13200	5700	7700	6700	0	5900
"	4000		10000	11400	11700	5700	6700	8600	6	5200
"	4000		8000	8800	8400	6700	7700	6700	12	5000
Navy Stockless	8000	49	15900	18800	21000	15300	14400	19100	0	15000
"	8000		15900	18600	19200	14400	15300	17200	6	14600
"	8000		13200	14300	15300	11500	13400	13400	12	14300
Navy Stockless	17000	49	33300	41600	46200	30600	38300	43100	0	34000
British Mulock	2110	33	5700	6500	6300	4700	4700	4700	0	—
Lightweight w/ fluke extension plates	2000	29	8400	9400	10300	7700	7700	8500	0	8100
	3000	30	11700	14900	16500	9600	13400	12400	0	9900
	4000	30	17300	20400	18800	12400	15300	15300	0	11900
New Design Baldt	3170	50	21000	30200	25400	12100	14000	13100	0	17400
"	3650	50	12800	14900	16600	9300	8400	8400	0	8500
Croseck	3060	51	23500	35600	41200	14300	21000	26000	0	17300

TABLE IV

Holding Power Data of Steel Anchors Tested in Beach Sand at Port Hueneme

Anchor	Wt-Lb	Fluke Angle	Average Holding Power length of drag 50-ft	90-ft	Minimum Holding Power length of drag 50-ft	90-ft
Lightweight	2000	29	26400	24500	21000	21000
"	3000	30	42000	43900	38200	40100
"	4000	30	52800	54500	49700	47800
"	10000	30	109600	127200	92500	120500
Navy Stockless	4000	45	8500	19400	5700	5700
"	8000	49	28300	27400	22900	15300
"	17000	49	66300	60800	57400	59300
British Mulock	2110	33	8500	9800	5700	5700
Lightweight w/ fluke extension	2000	29	31200	32400	30500	24800
	3000	30	48400	49700	40100	45100
	4000	30	62400	73700	59300	65000
New Design Baldt	3170	50	31100	27700	22900	17200
"	3650	50	43000	41400	11400	5700
Croseck	3060	51	18700	12300	13500	11400

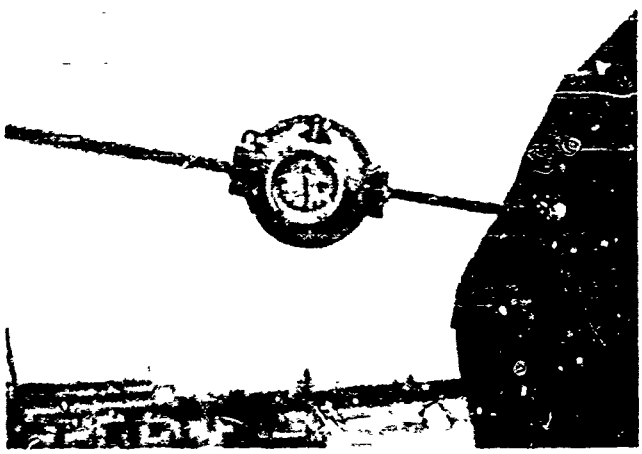


Figure 2. Strain gage used to measure breakout force of anchors in mud bottom.

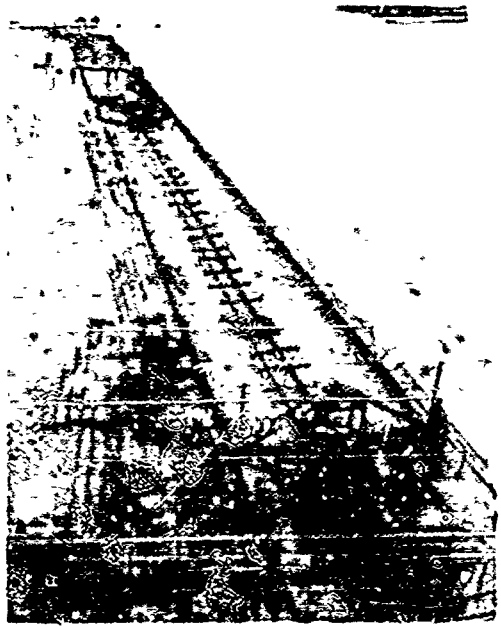


Figure 3. Test apparatus used to pull anchors in beach sand.

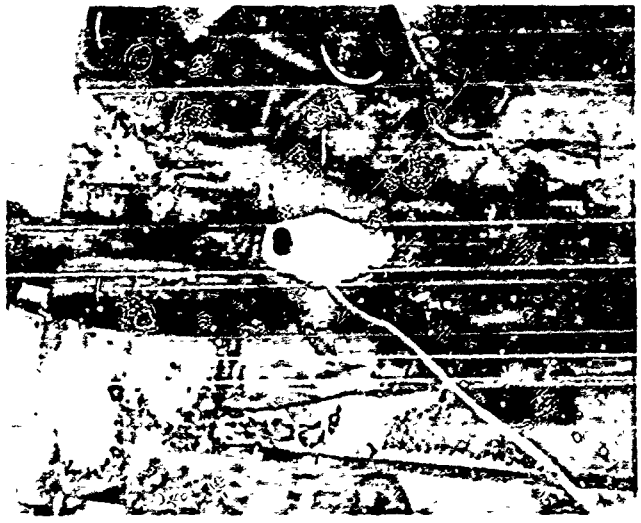


Figure 4. 500,000-lb. capacity electrical dynamometer.

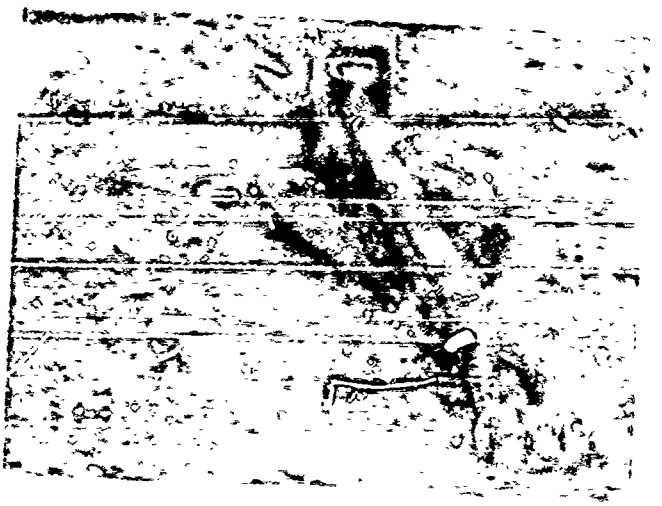


Figure 5. Typical LWT anchor. Note curved shape of the upper portion of flukes between the stock and the flukes.

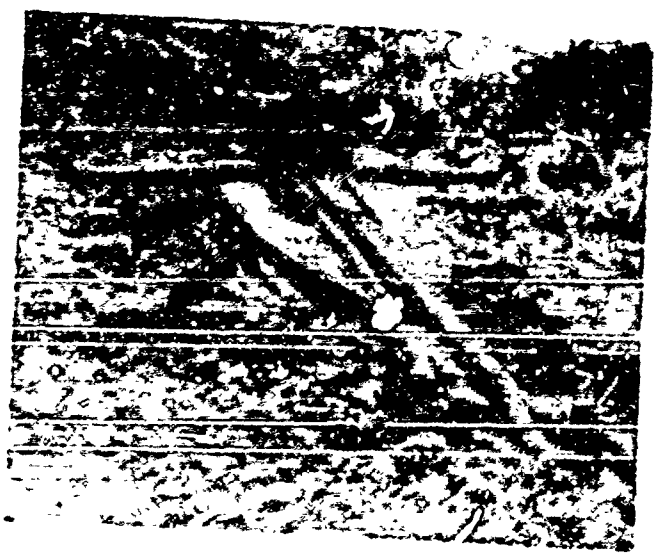


Figure 6. 10,000-lb. LWT anchor.

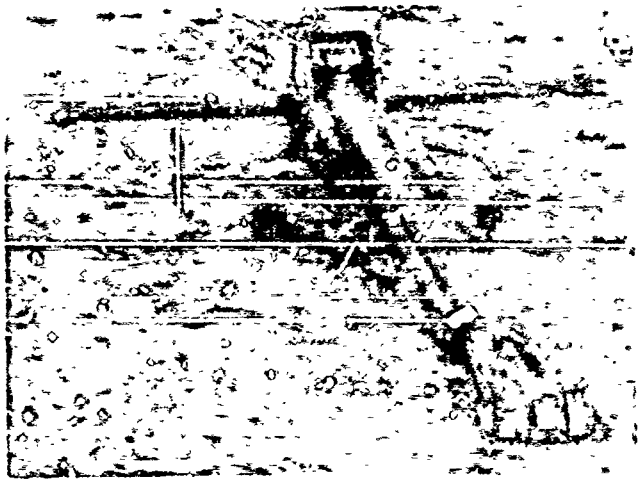


Figure 5. Typical LWT anchor. Note curved shape of the upper portion of flukes between the stock and the flukes.

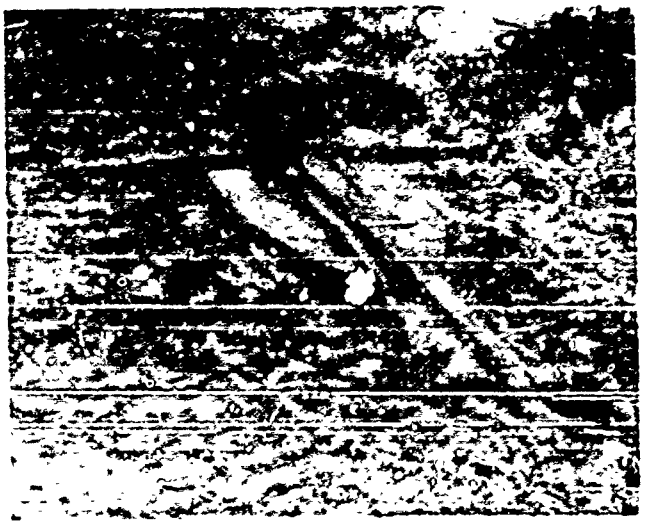


Figure 6. 10,000-lb. LWT anchor.

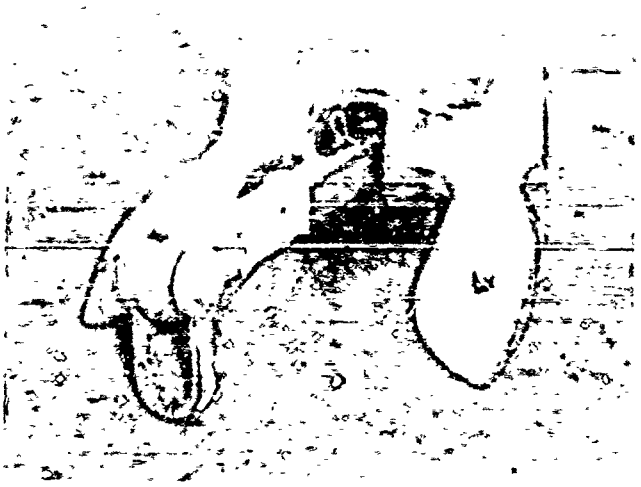


Figure 7. 4,000-lb. Navy Stockless anchor.

Figure 8. 8,000-lb. Navy Stockless anchor.

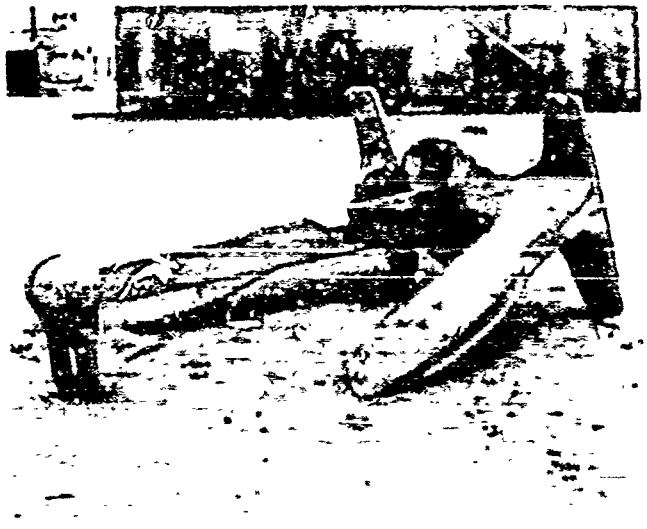


Figure 9. 17,000-lb. Navy Stockless anchor.

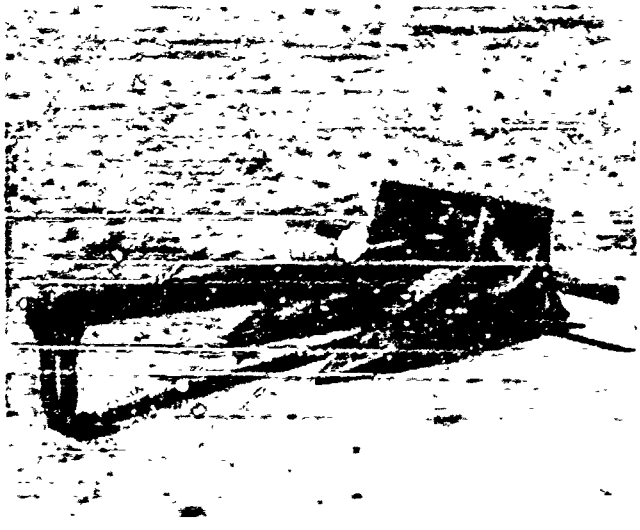


Figure 10. 2,110-lb Hulock anchor.

Figure 11. Typical LWT anchor with fluke extension plates.

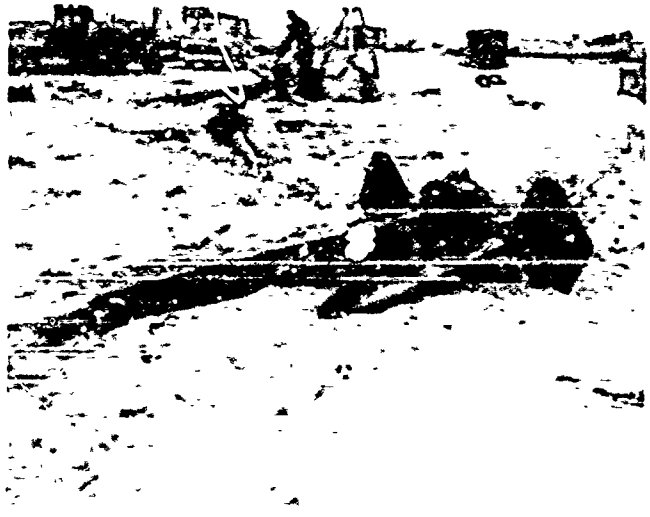


Figure 12. New design Baldt mud anchor.

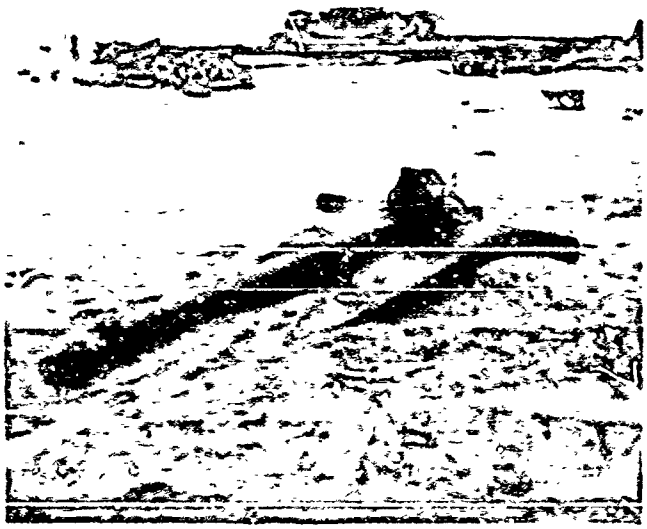


Figure 13. New design 3,650-lb. Baldt mud anchor.

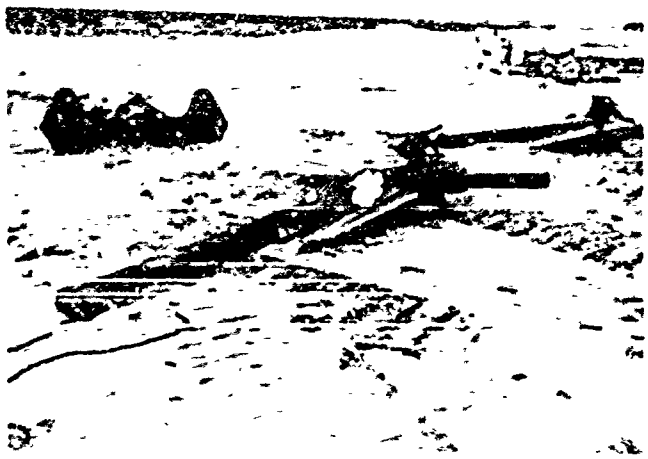


Figure 14. Croseck anchor, 3,060-lb.

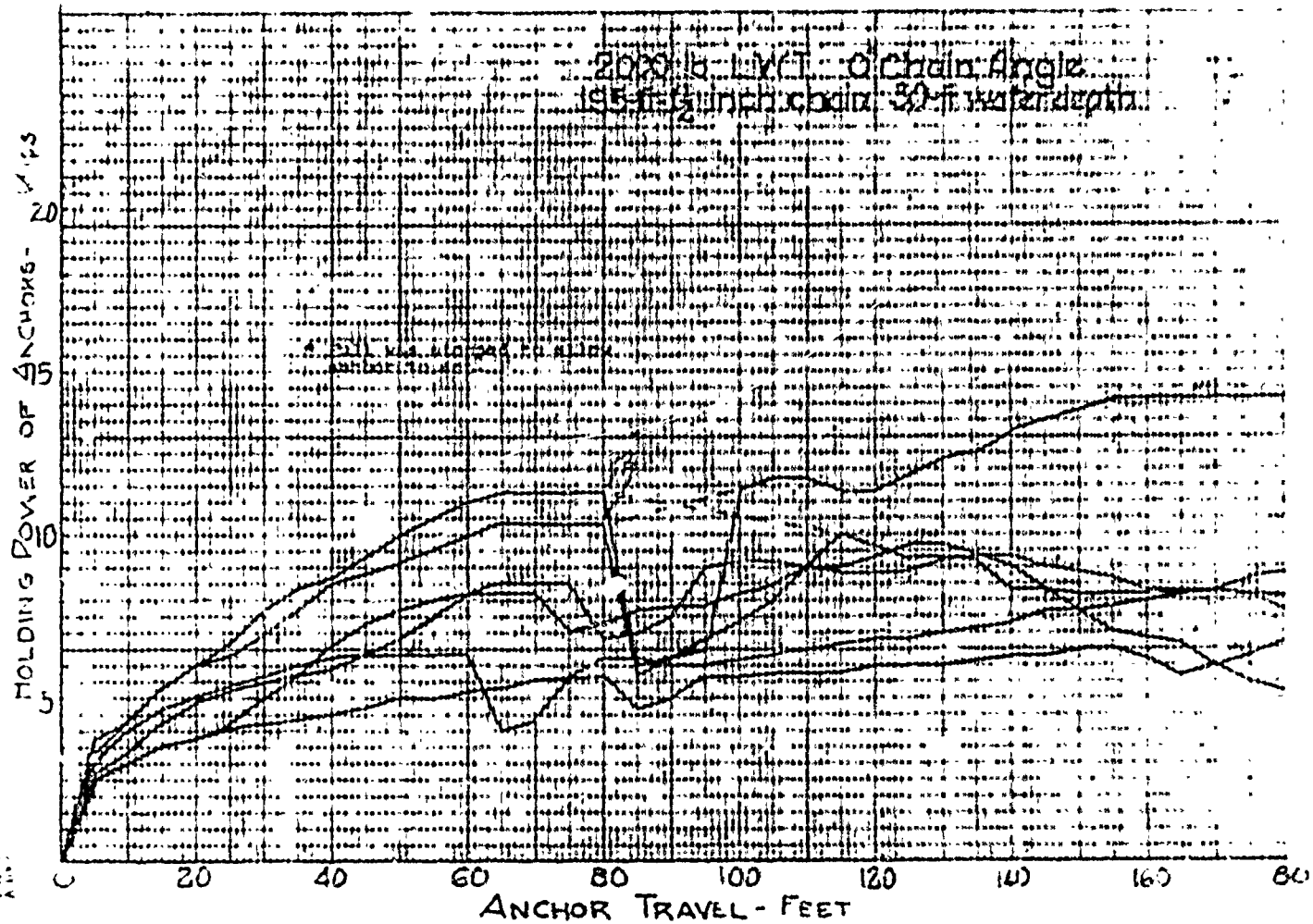
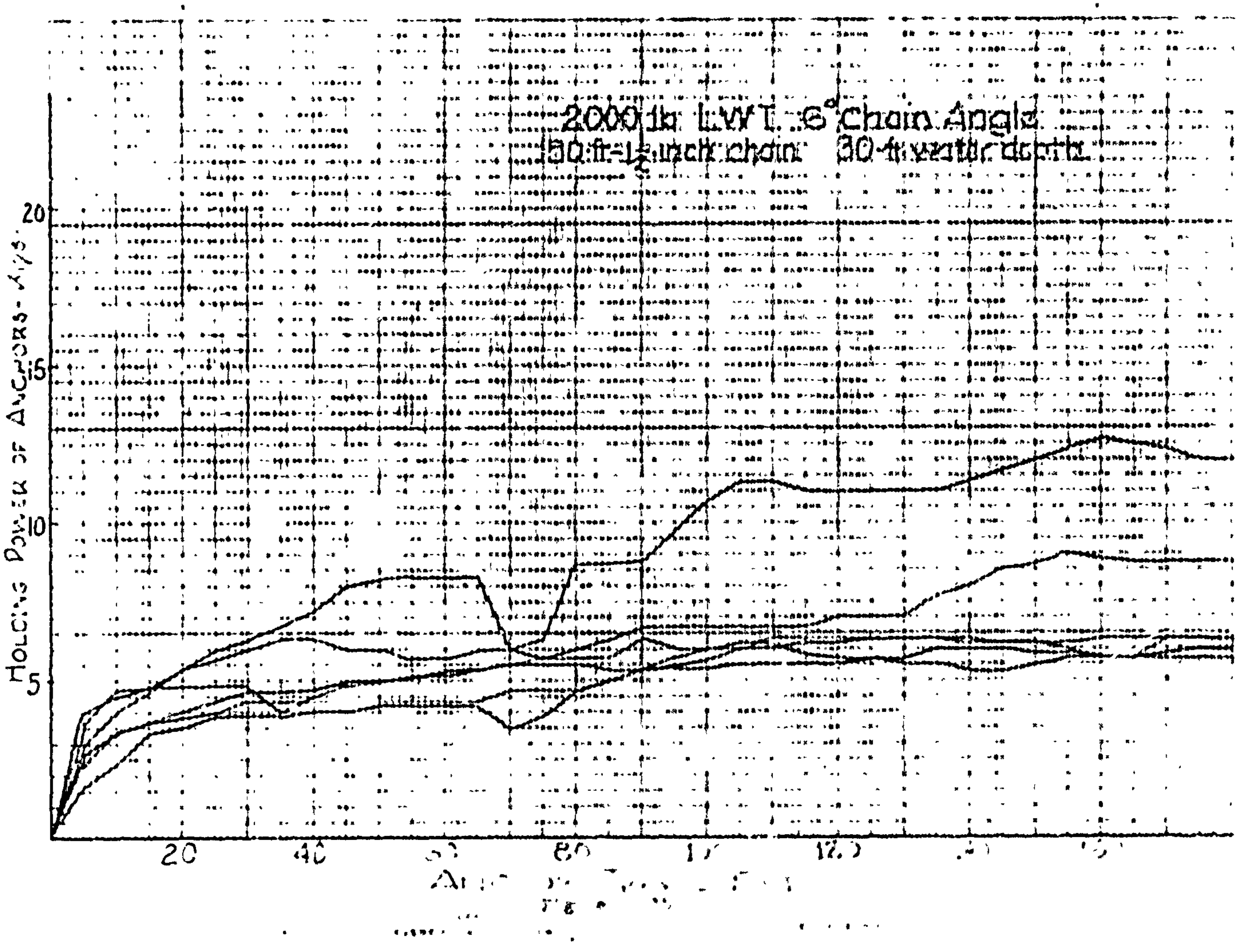
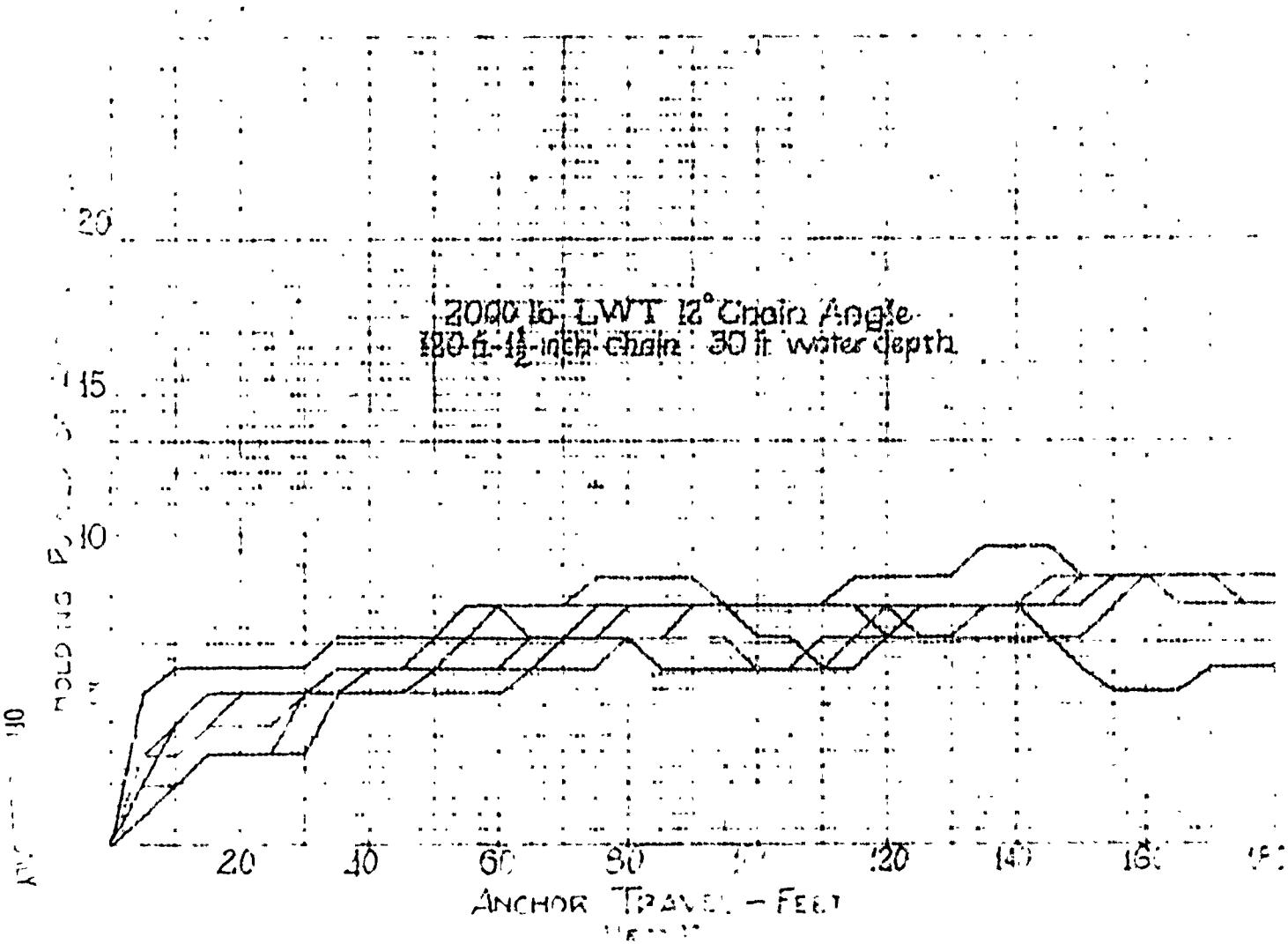
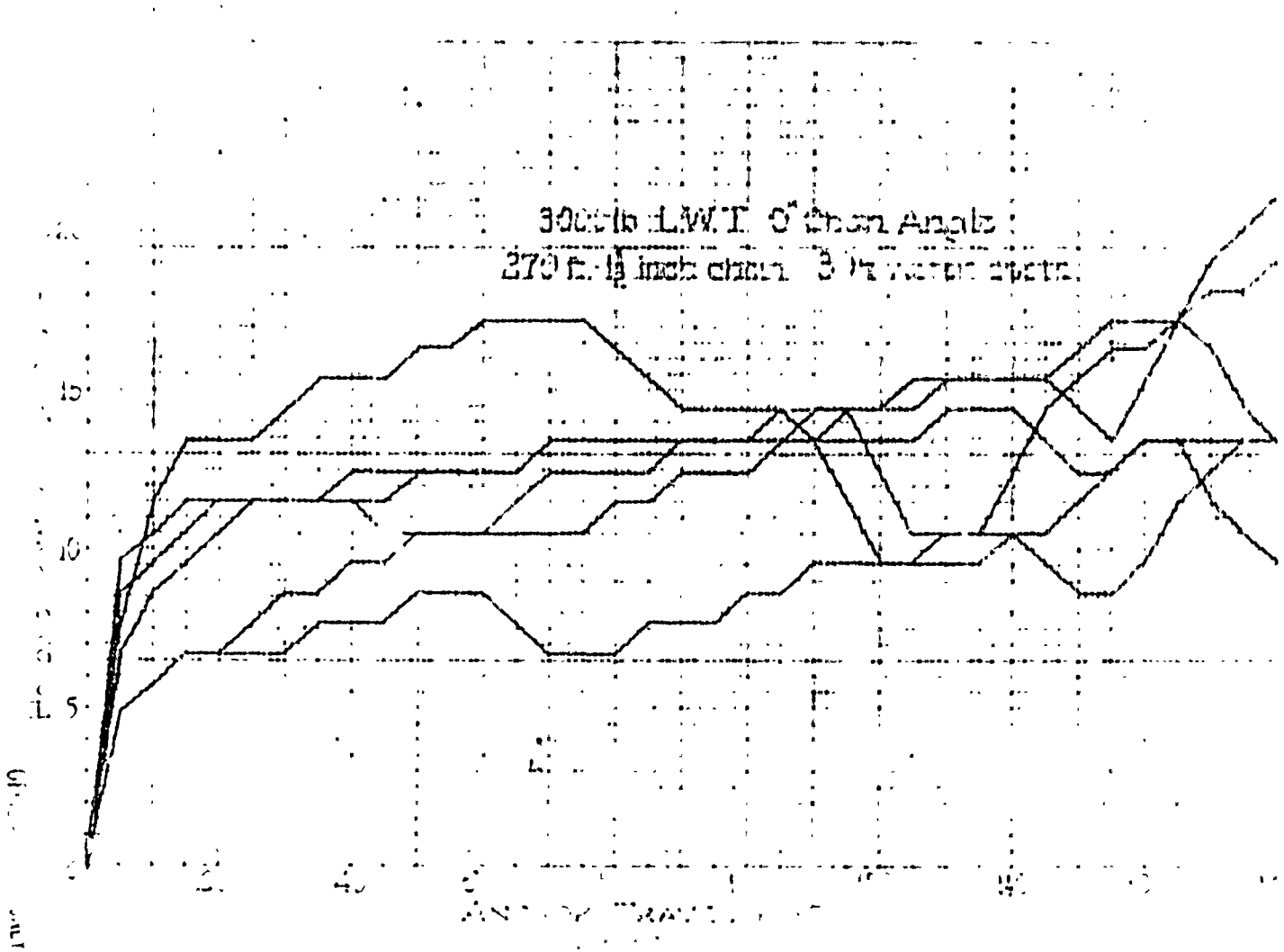
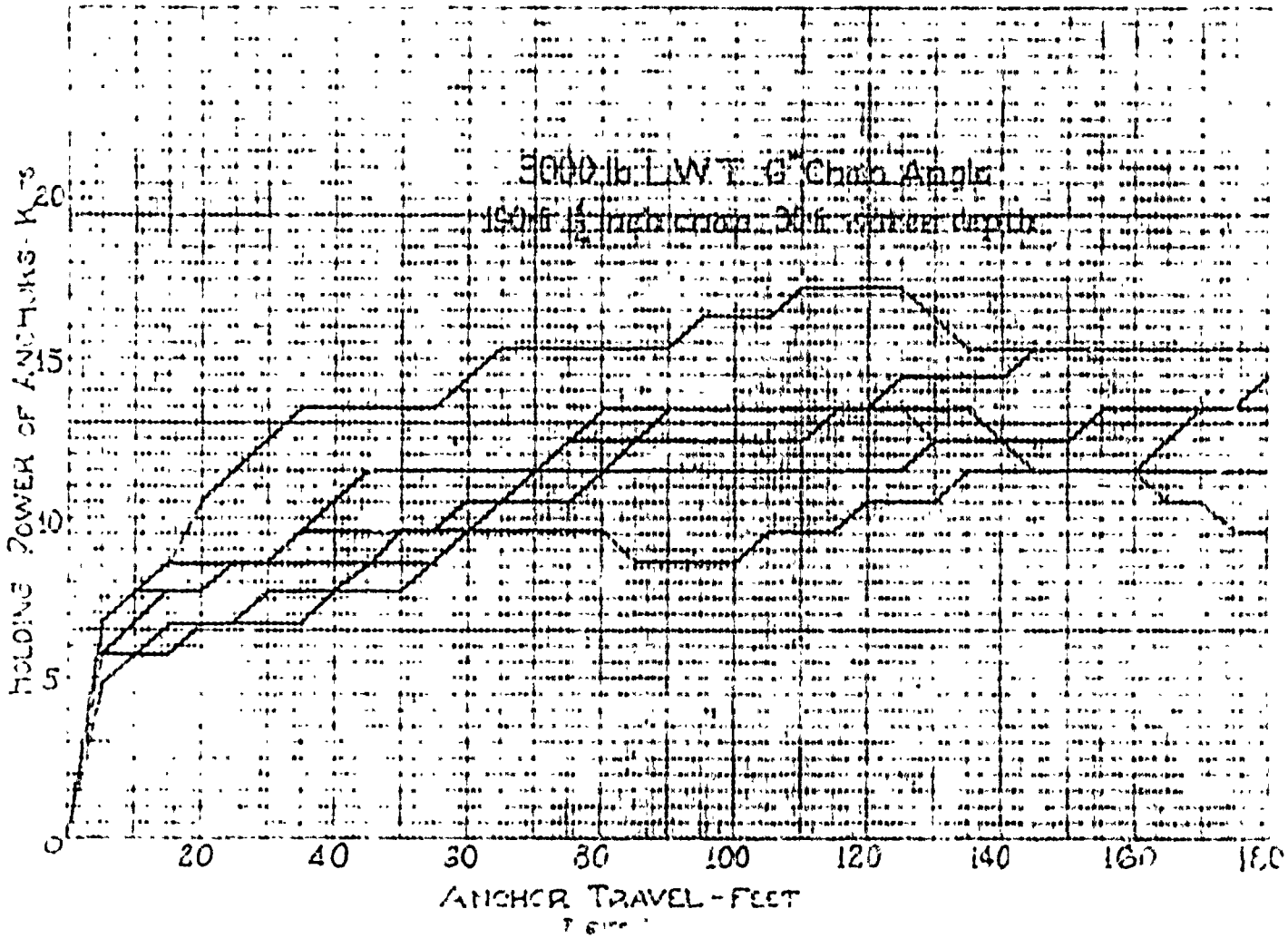

2000 lb. LWT. 0° Chain Angle
1 5/8 inch chain 30 Feet water depth
HOLDING POWER OF ANCHORS - KIPS
0
5
10
15
20
0
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET

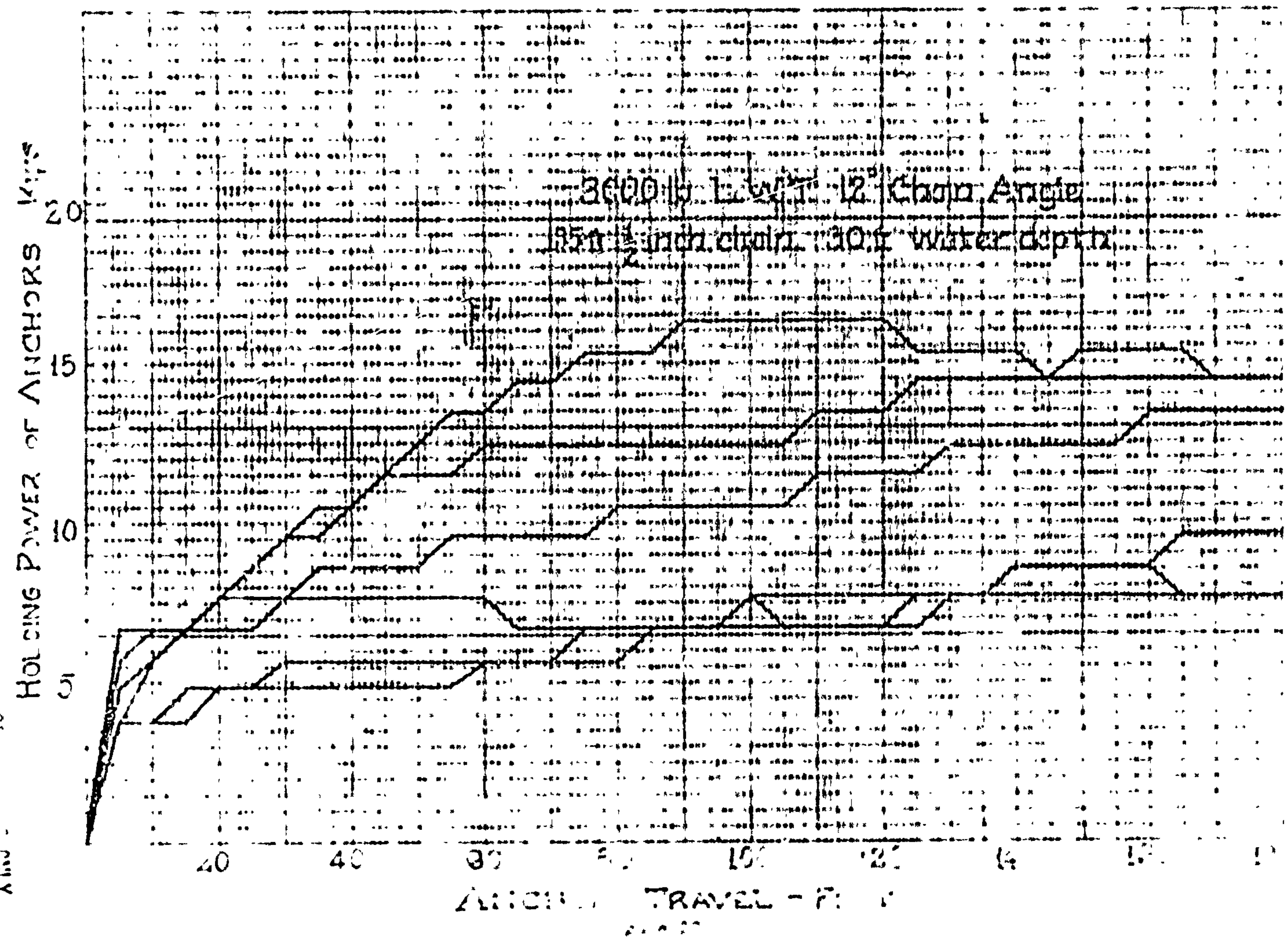
Figure 15

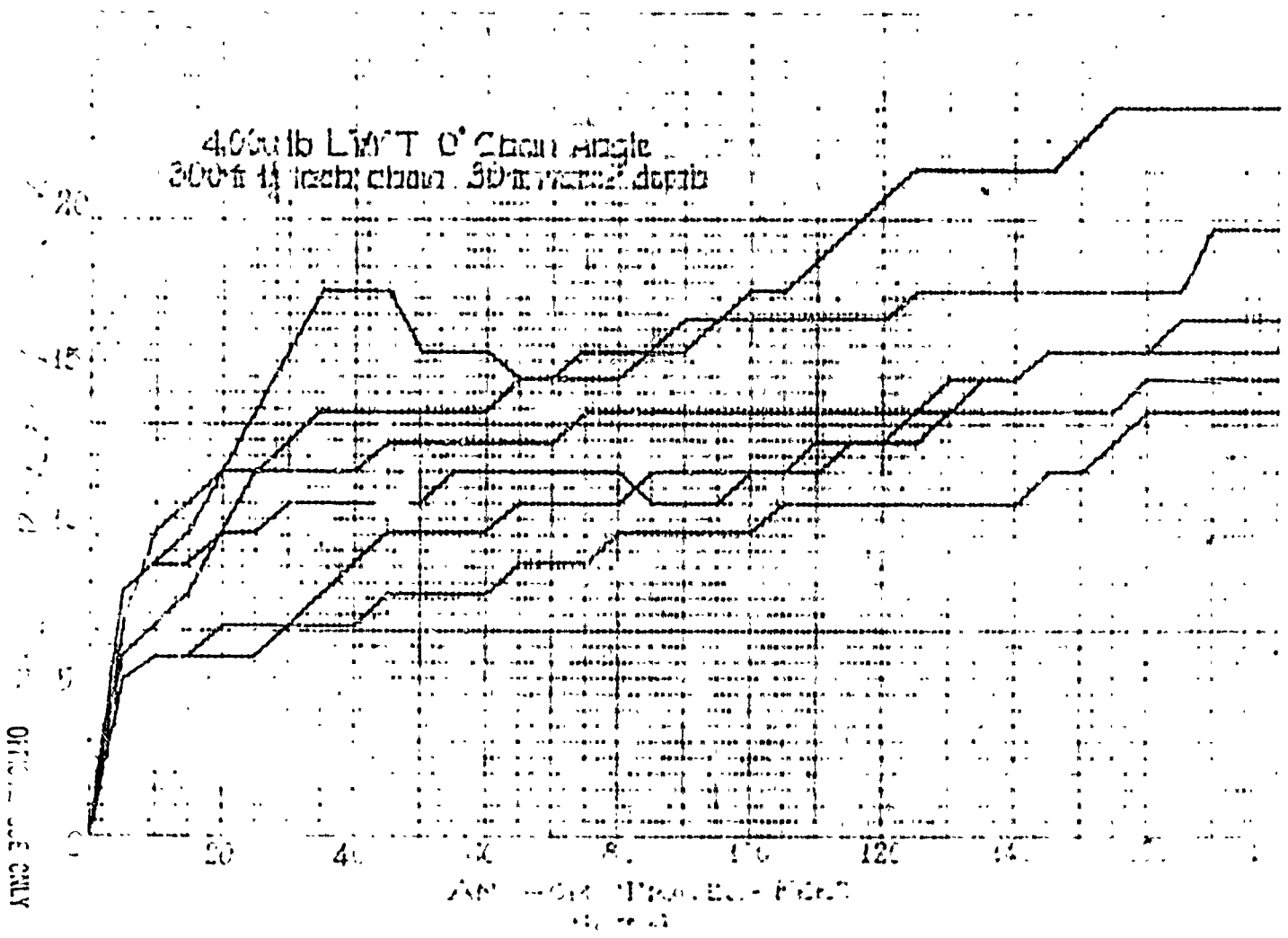

2000 lb LWT 6° Chain Angle
150 ft-1½ inch chain 30 ft water depth
Holding Power of Anchors - Kips
20
15
10
5
20
40
80
120

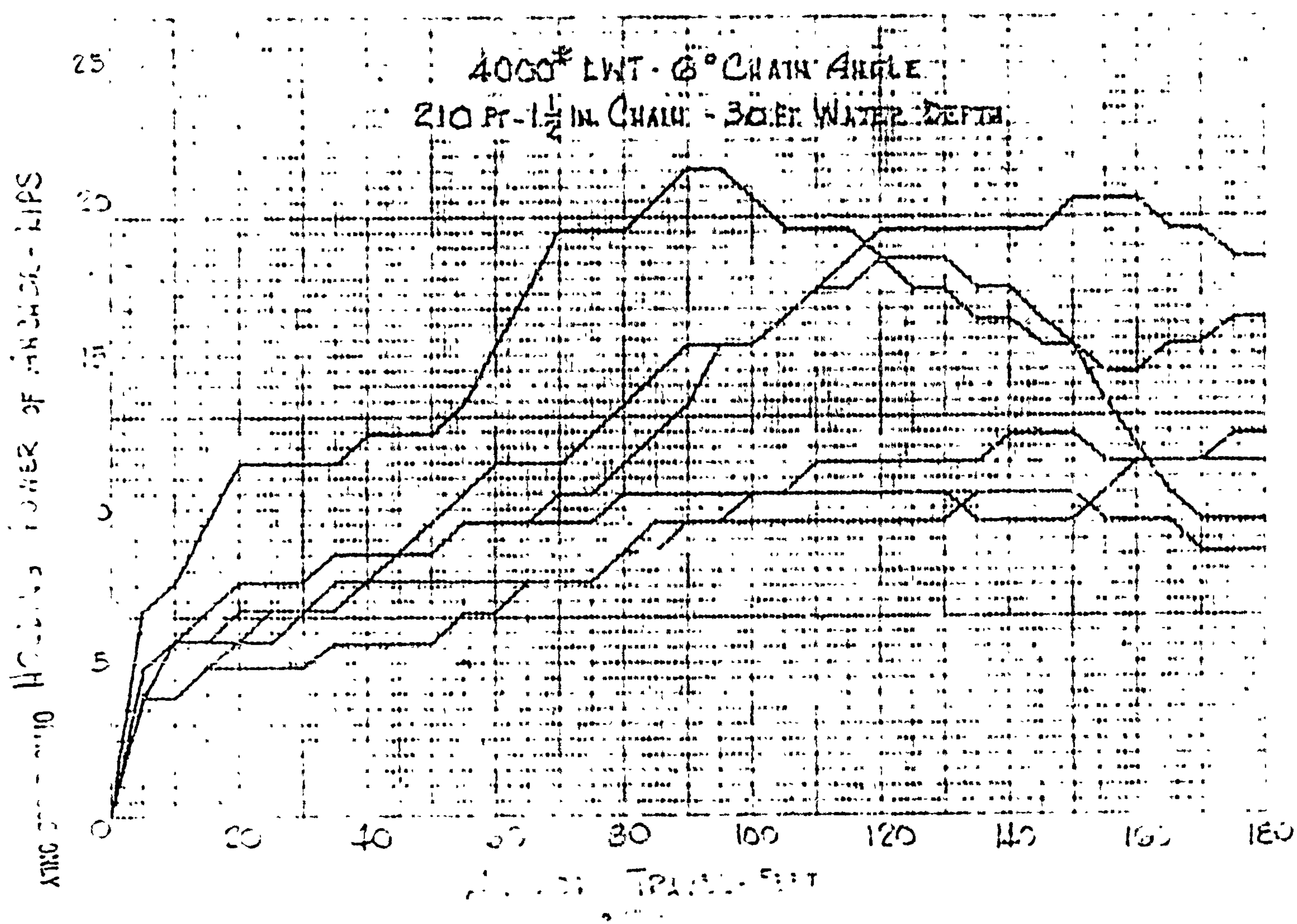

20
15
10
2000 lb. LWT 12° Chain Angle
180-ft-1½-inch chain 30 ft water depth
20
40
60
80
120
140
160
ANCHOR TRAVEL – FEET


15
10
5

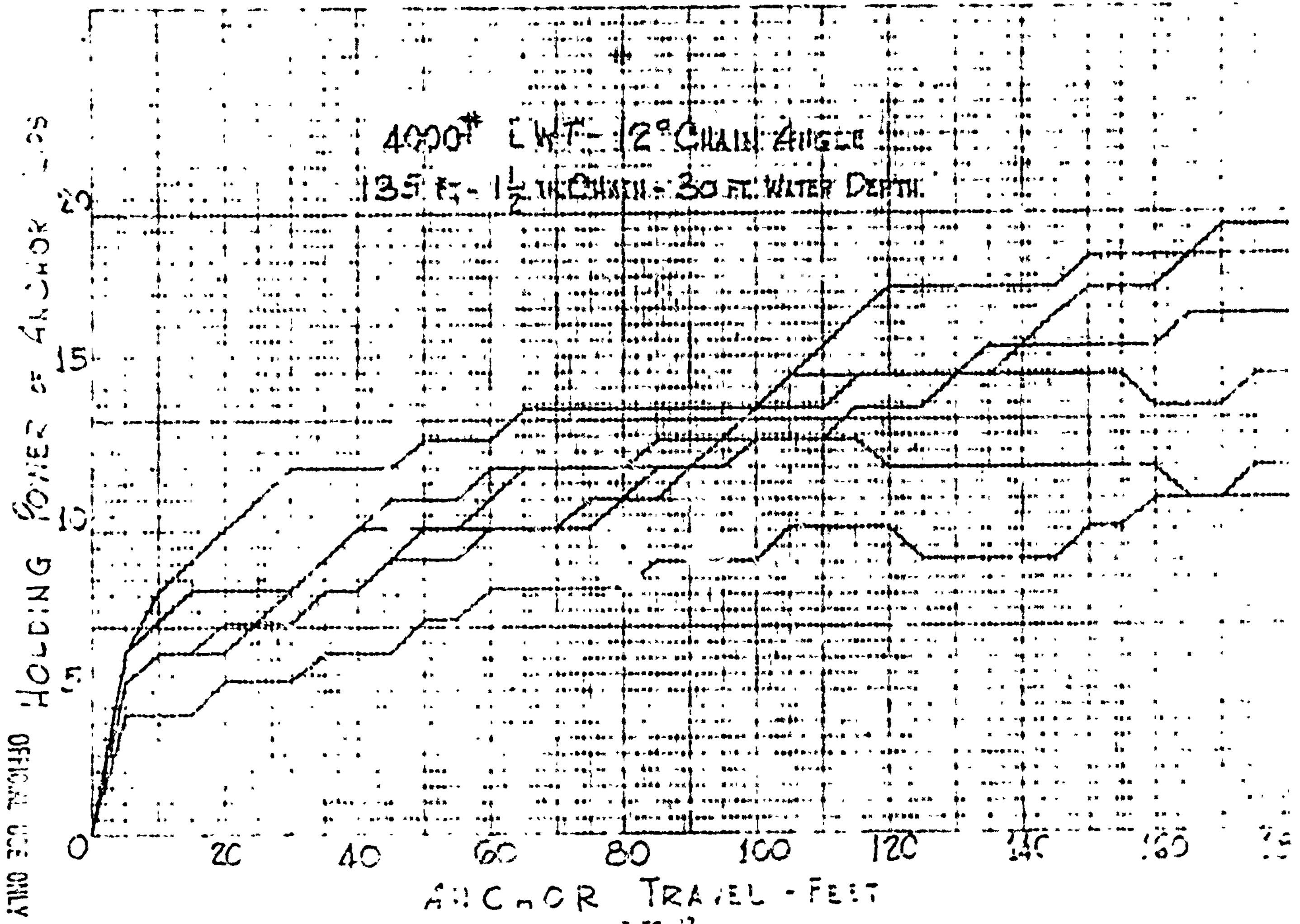

3000 lb. L.W.T. 6° Chain Angle
150 ft. 1½ inch chain - 30 ft. water depth
HOLDING POWER OF ANCHORS - K
0
5
10
15
20
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET


3600 lb LWT 12° Chain Angle
85 ft 1/2 inch chain 30 ft water depth
HOLDING POWER OF ANCHORS Kips
20
15
10
5
20
40
60
100
120
TRAVEL


20
15
5
0
20
40
120



4000# LWT · 6° CHAIN ANGLE
210 FT - 1½ IN. CHAIN - 30 FT. WATER DEPTH
25
5
0
20
40
30
100
120
180



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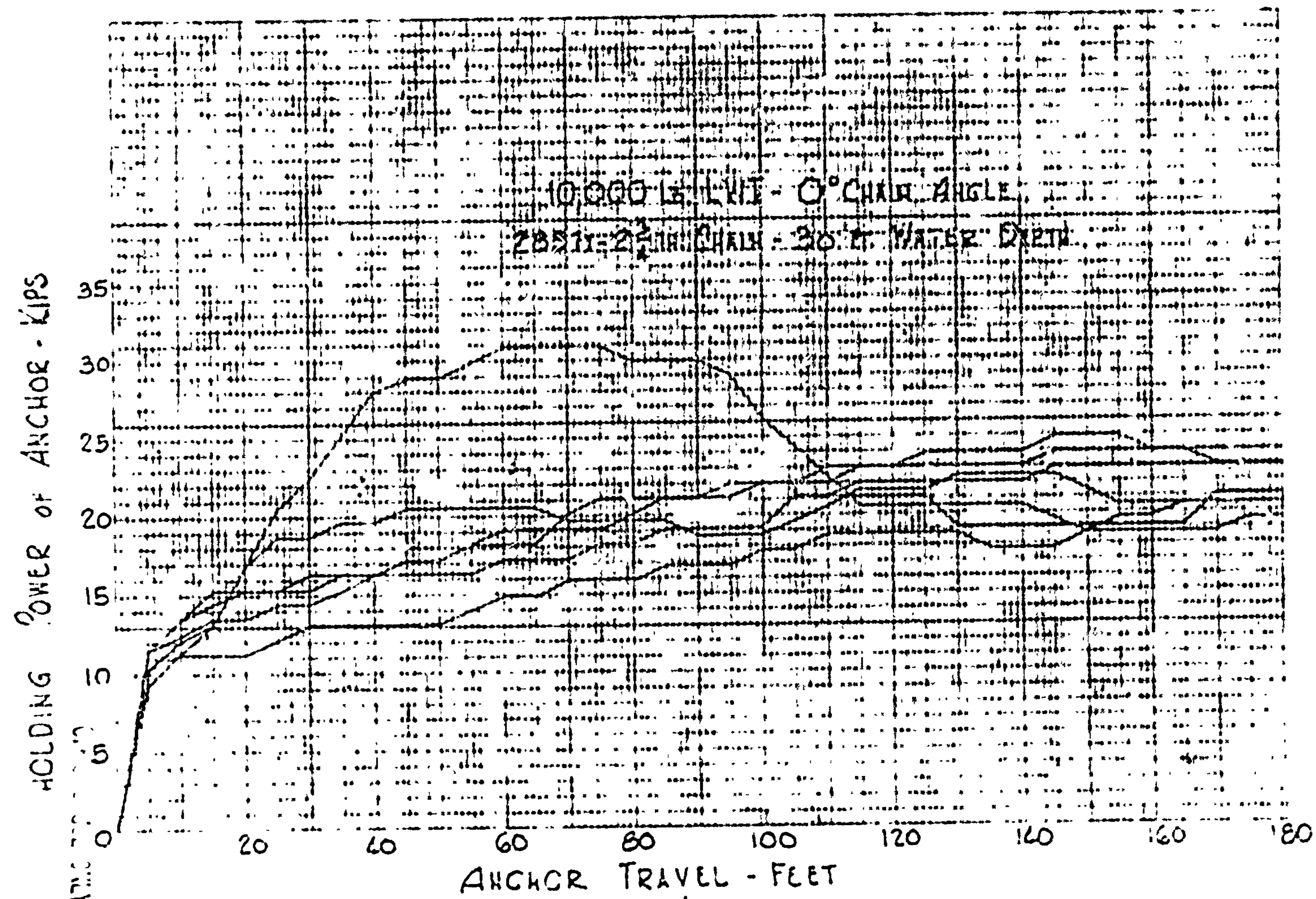
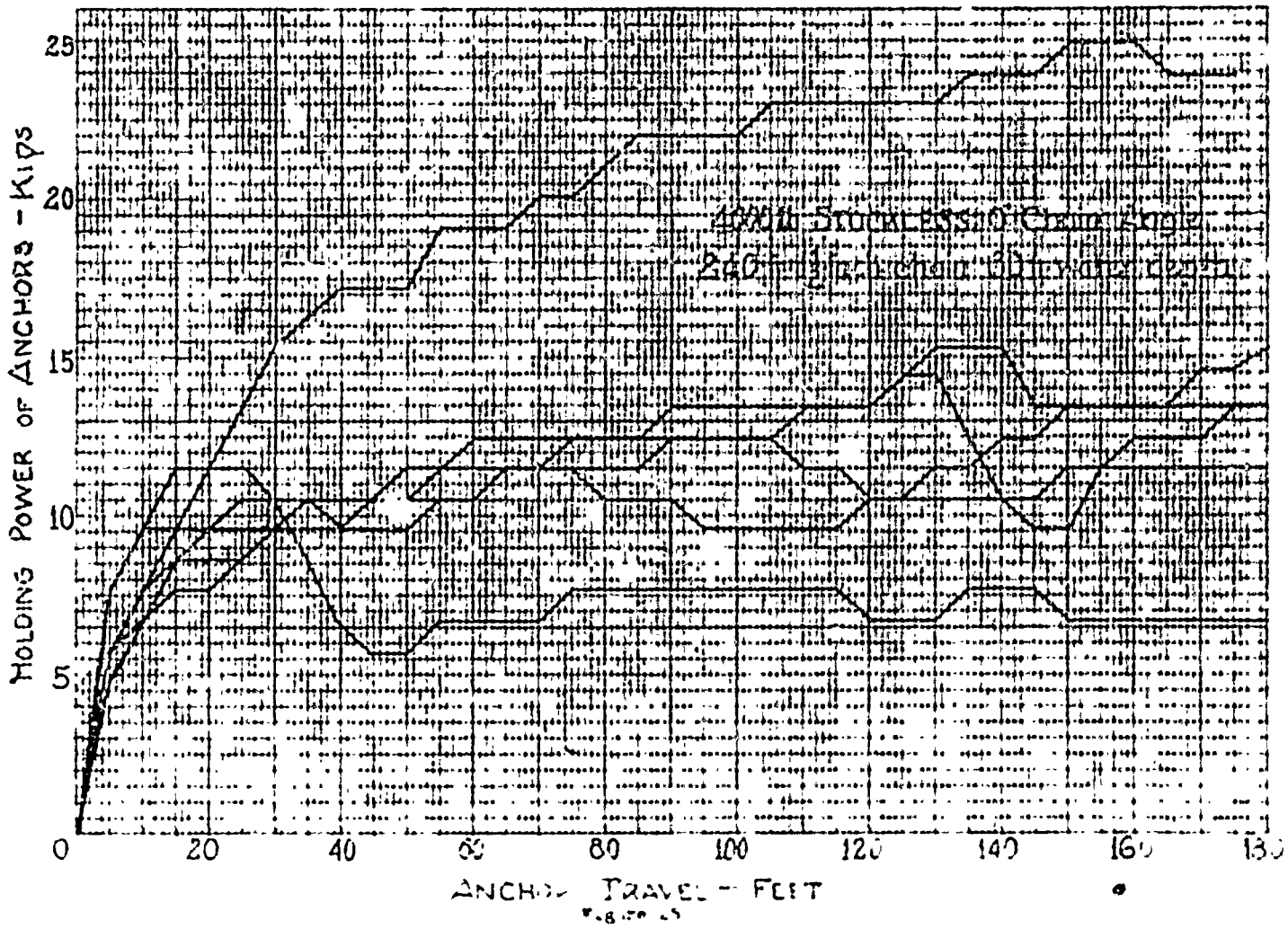

10,000 LB. LWT - 0° CHAIN ANGLE
2 3/4 IN. CHAIN - 30 FT. WATER DEPTH
HOLDING POWER OF ANCHOR - KIPS
0
5
10
15
20
25
30
35
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET

Figure 24


HOLDING POWER OF ANCHORS - KIPS
25
20
15
10
5
0
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET
4000 lb STOCKLESS Chain Anchor
240 ft 3/4" chain 30 ft water depth

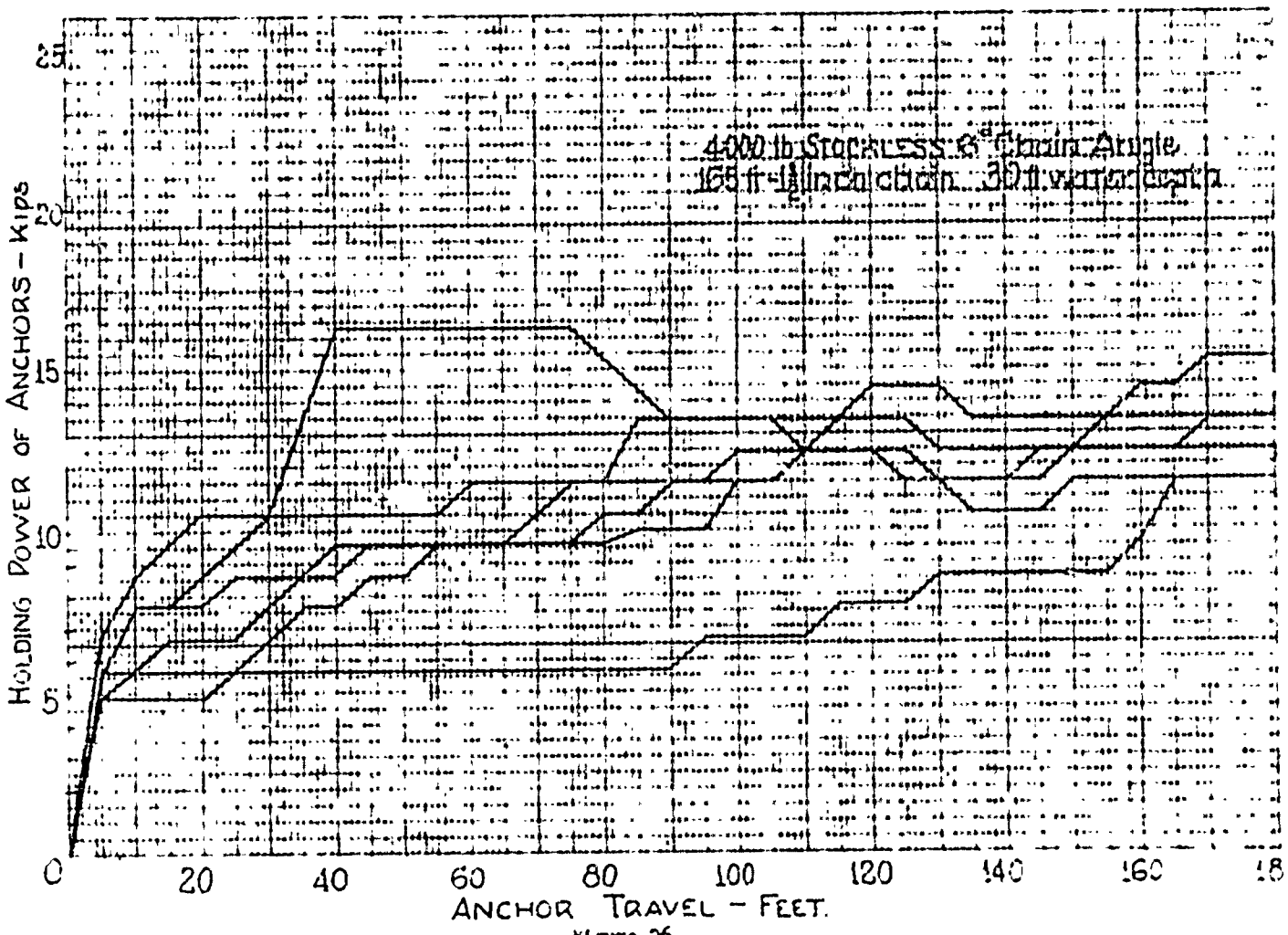
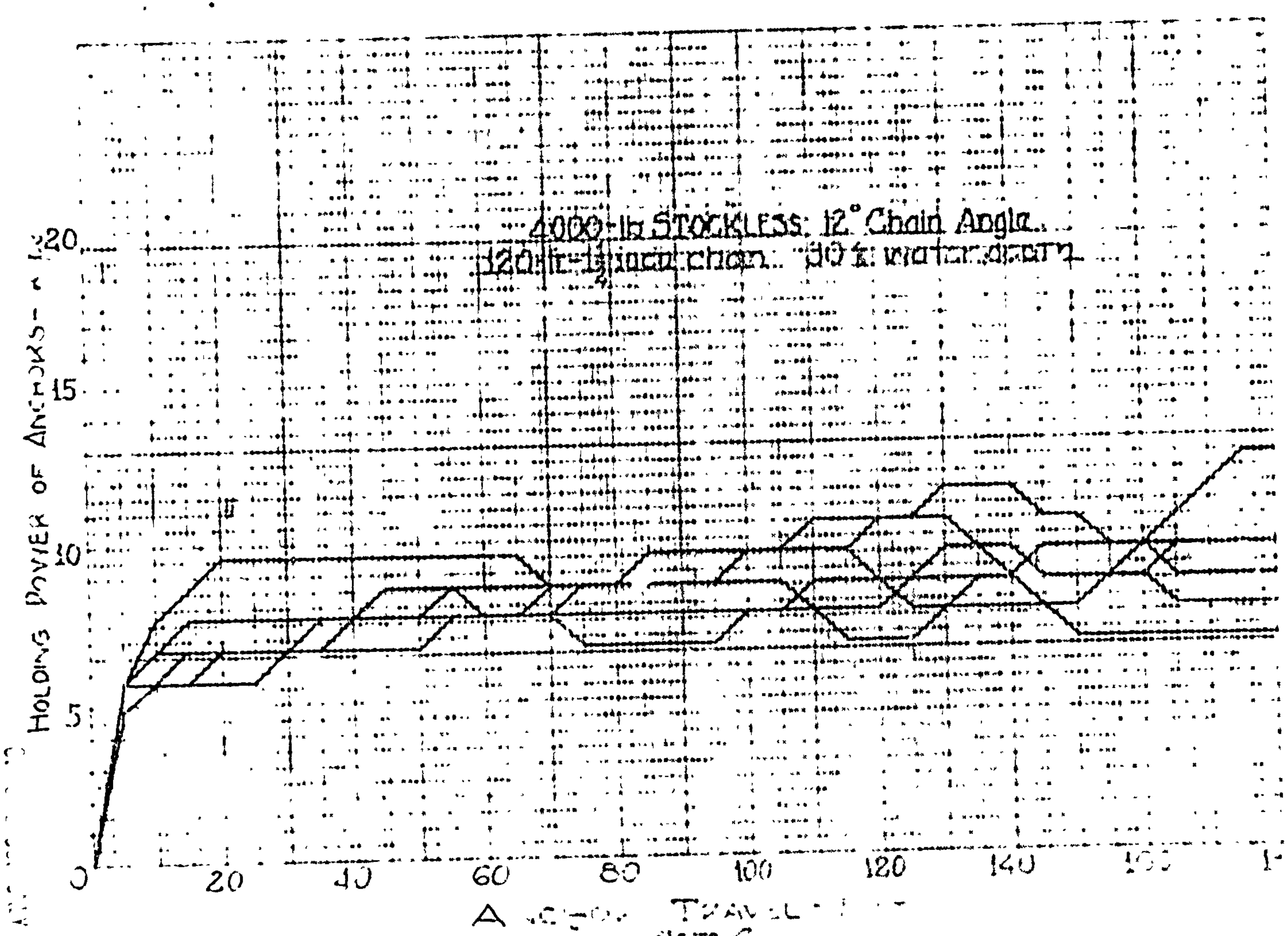

4000 lb Stockless 3/4" Chain Anchor
165 ft - 1/2 inch chain 30 ft water depth
HOLDING POWER OF ANCHORS - KIPS
0
5
10
15
20
25
0
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET.

Figure 26



4000-lb STOCKLESS; 12° Chain Angle
120 ft-1½ inch chain 30 ft water depth
HOLDING POWER OF ANCHORS
0
5
10
15
20
20
40
60
80
100
120
140
A
TRAVEL

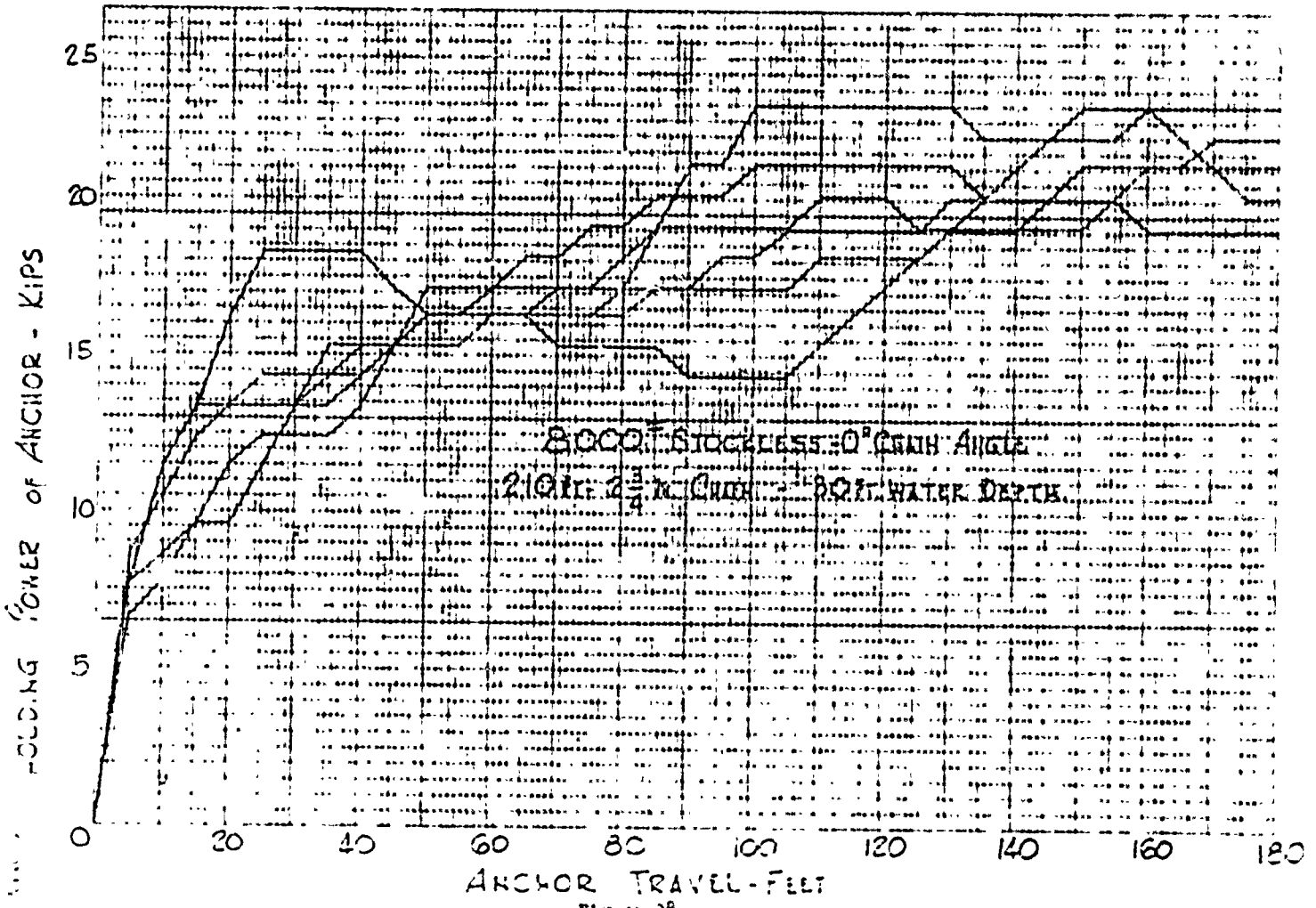
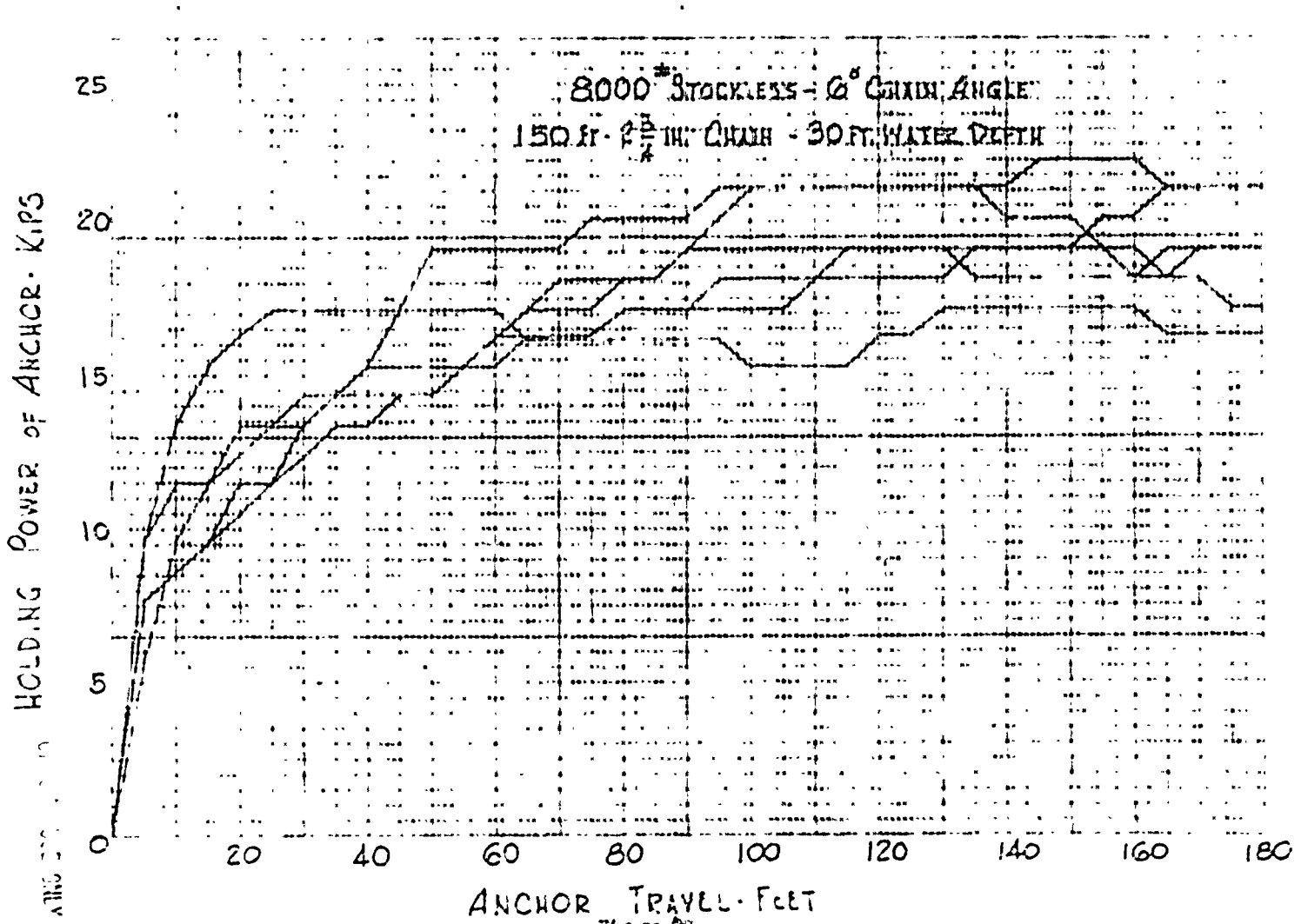
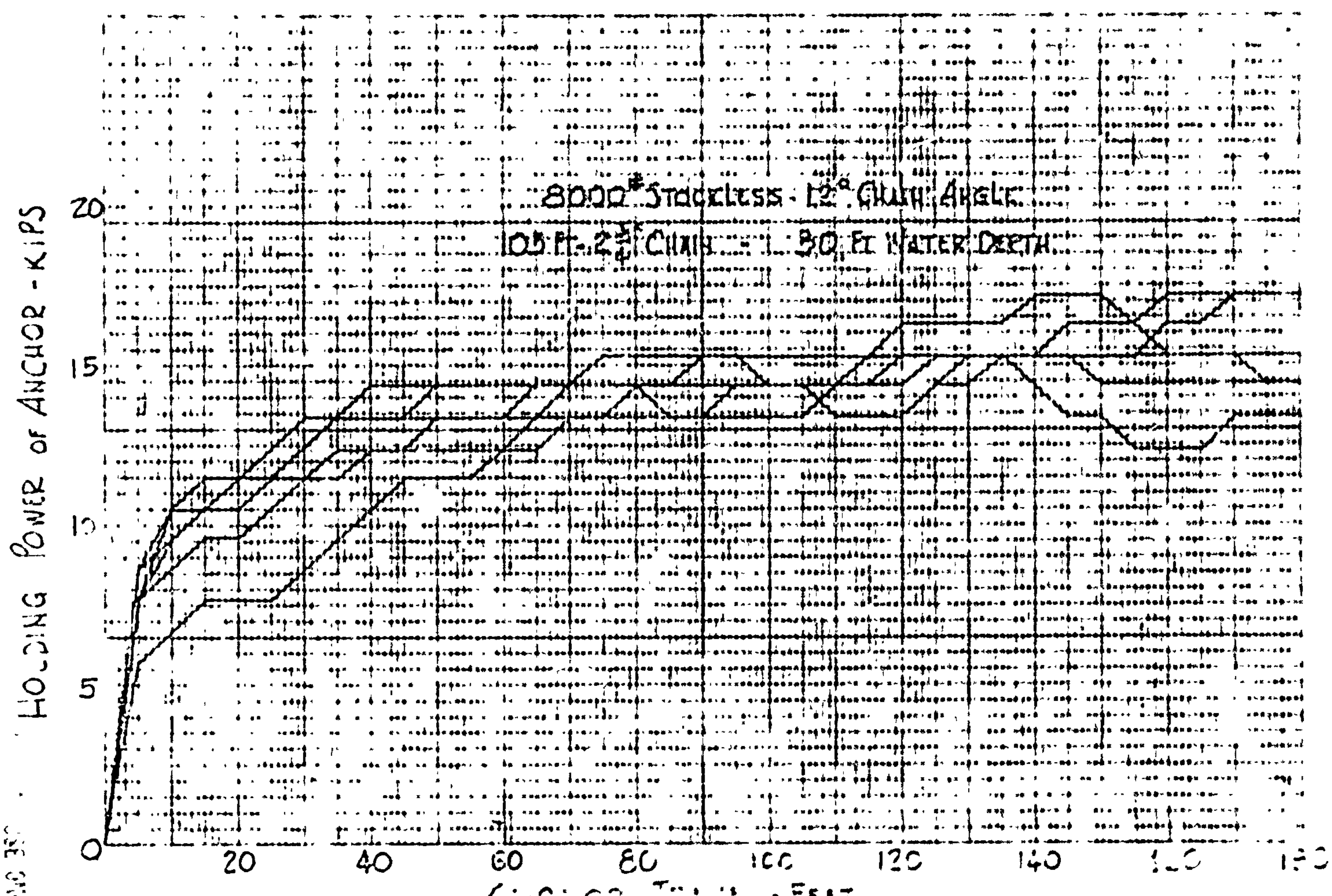

HOLDING POWER OF ANCHOR - KIPS
0
5
10
15
20
25
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET
BOCOT STOCKLESS 0° CRUH ANGLE
2.10 FT. 2 3/4 IN. CRUH 80 FT. WATER DEPTH

Figure 28


8000# STOCKLESS - 60° CHAIN ANGLE
150 ft - 2 1/8 IN. CHAIN - 30 FT. WATER DEPTH
HOLDING POWER OF ANCHOR - KIPS
0
5
10
15
20
25
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET
Figure 29



8000# Stockless - 12° Chain Angle
105 Ft - 2 3/4" Chain - 30 Ft Water Depth
Holding Power of Anchor - Kips
0
5
10
15
20
20
40
60
80
100
120
140
Anchor Travel - Feet

Figure 30

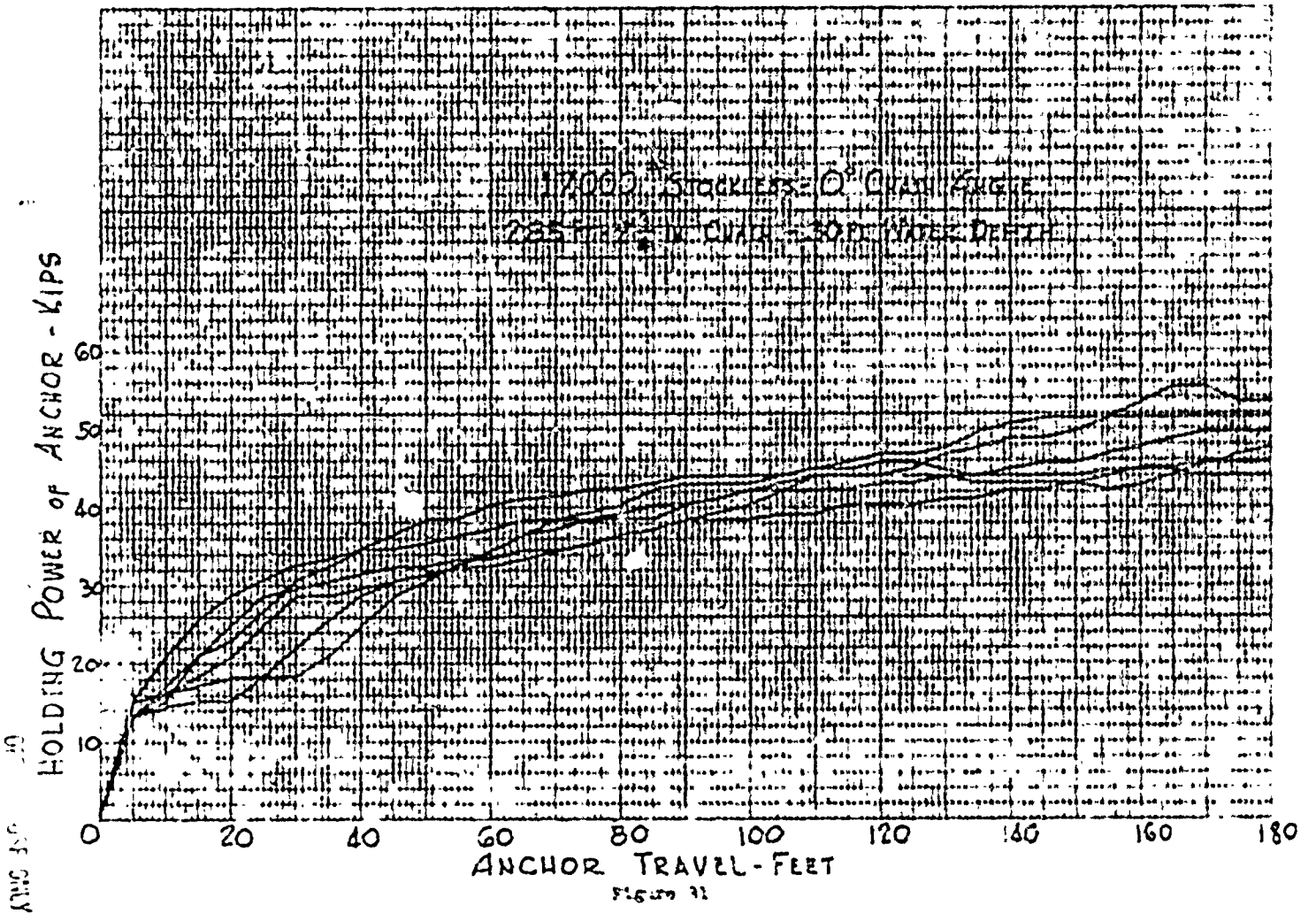

HOLDING POWER OF ANCHOR - KIPS
0
10
20
30
40
50
60
0
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET

Figure 31

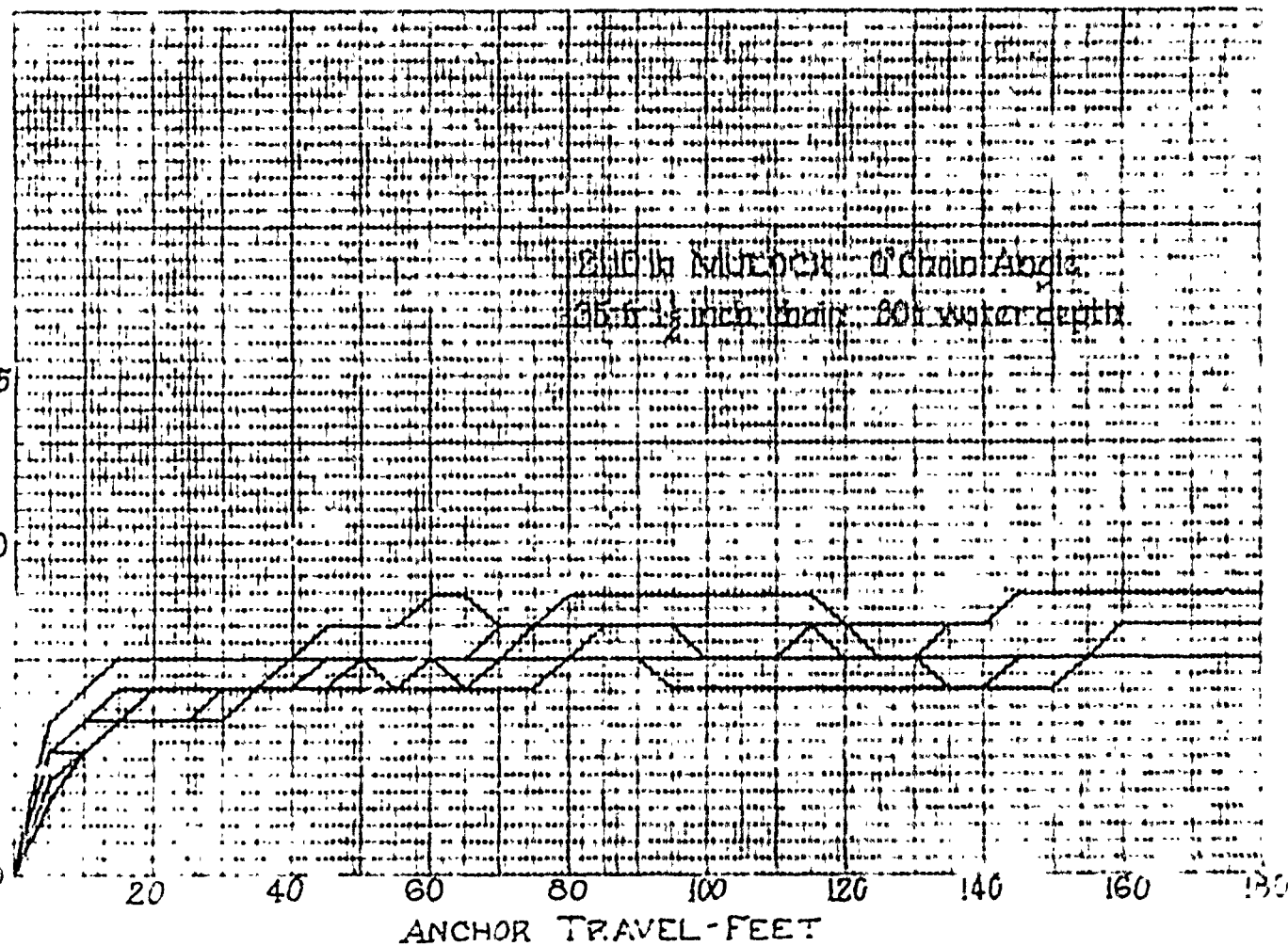

HOLDING POWER OF ANCHORS - Kips
0
5
10
15
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET

Figure X

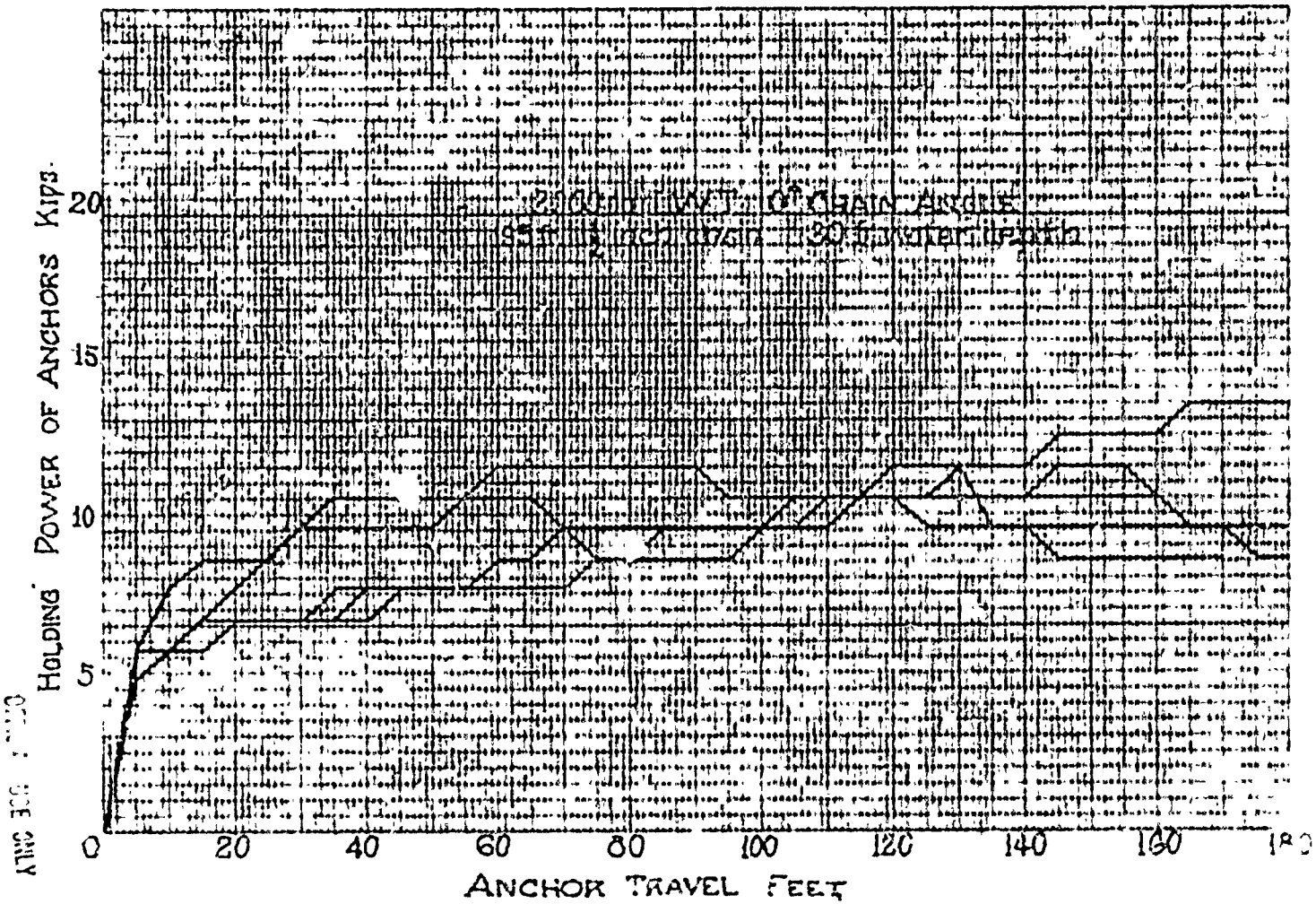

HOLDING POWER OF ANCHORS KIPS
0
5
10
15
20
20
40
60
80
100
120
140
160
ANCHOR TRAVEL FEET

Figure 33

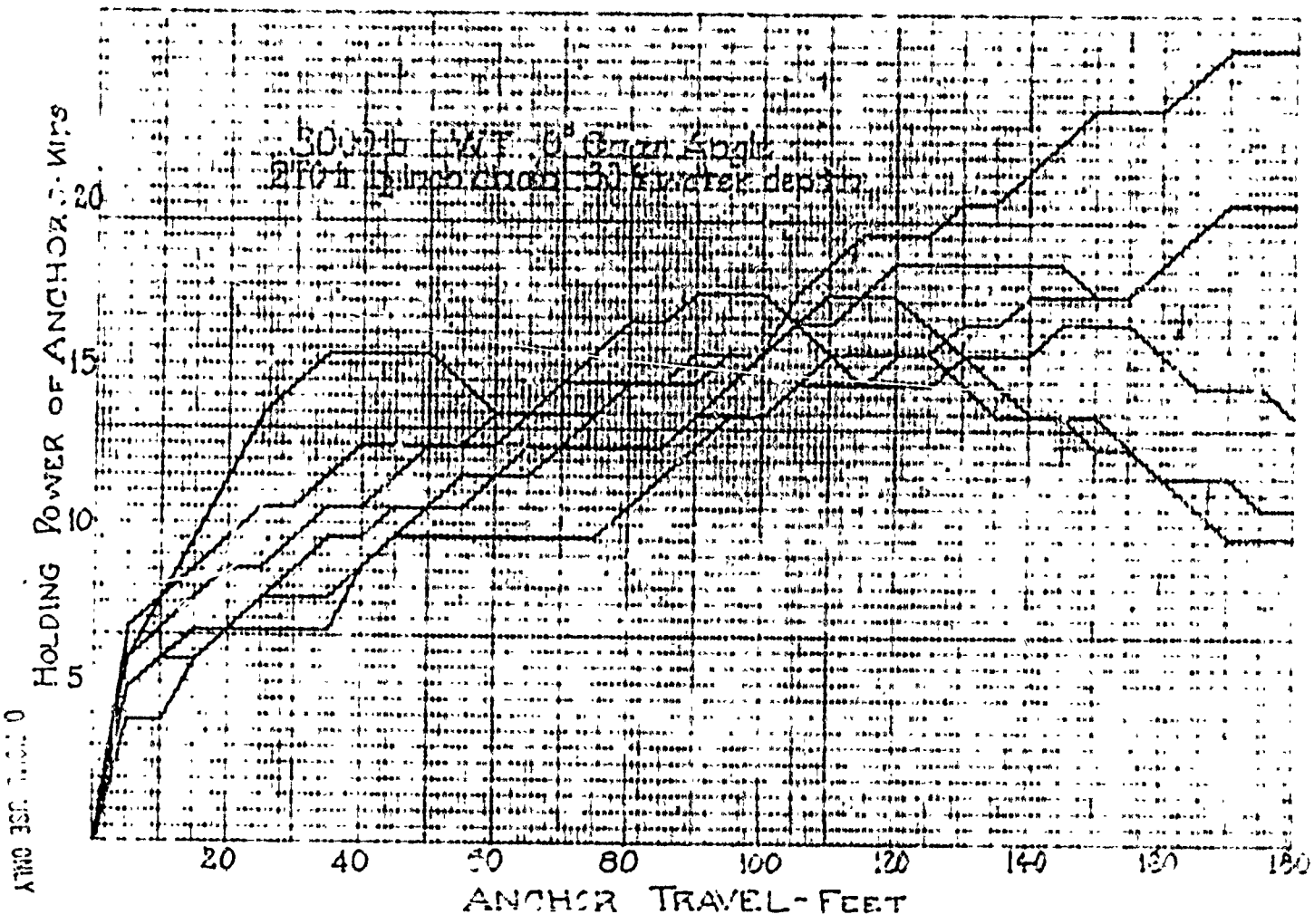

HOLDING POWER OF ANCHOR - KIPS
5
10
15
20
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET

Figure 3-

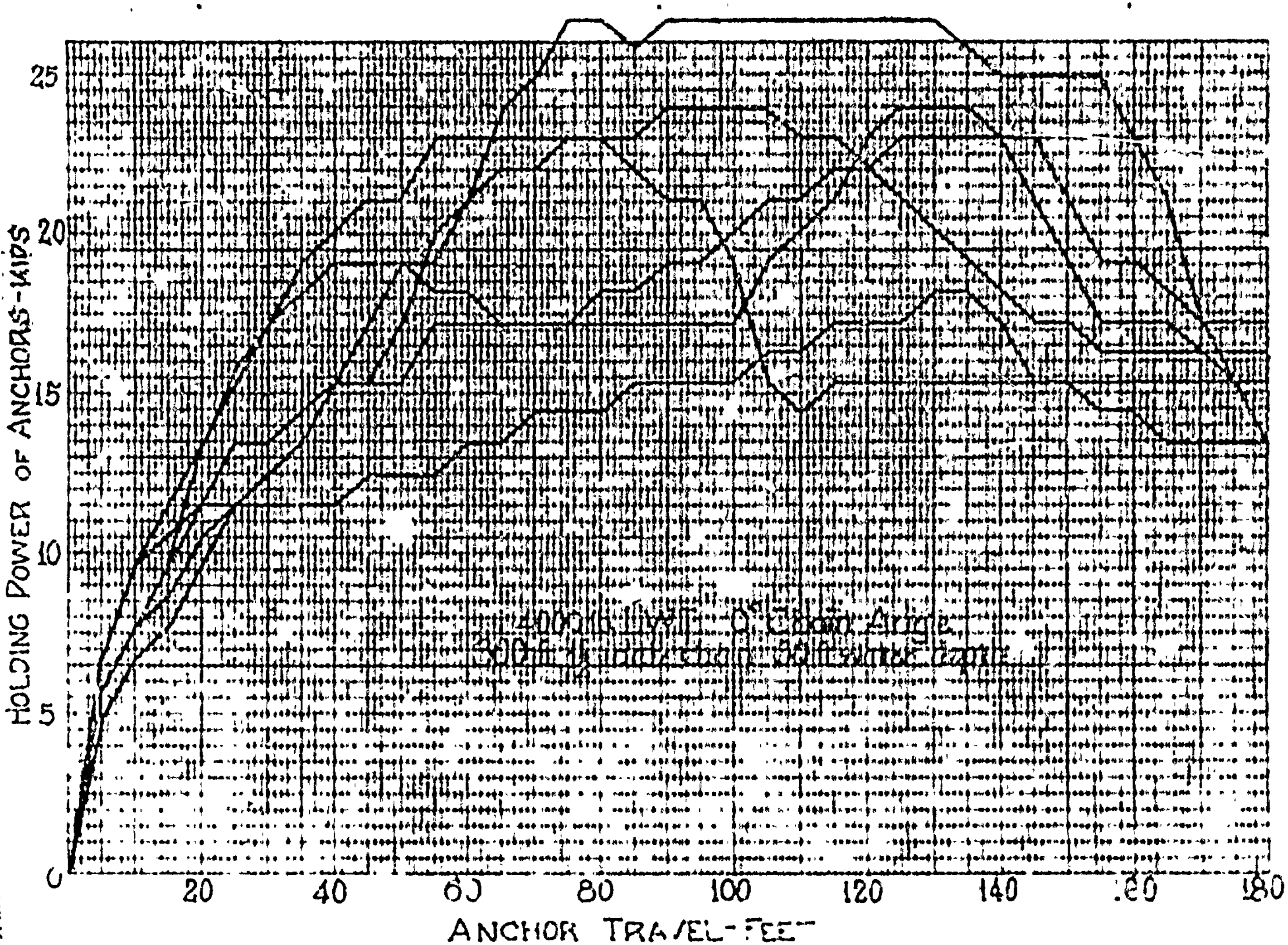


Figure 35

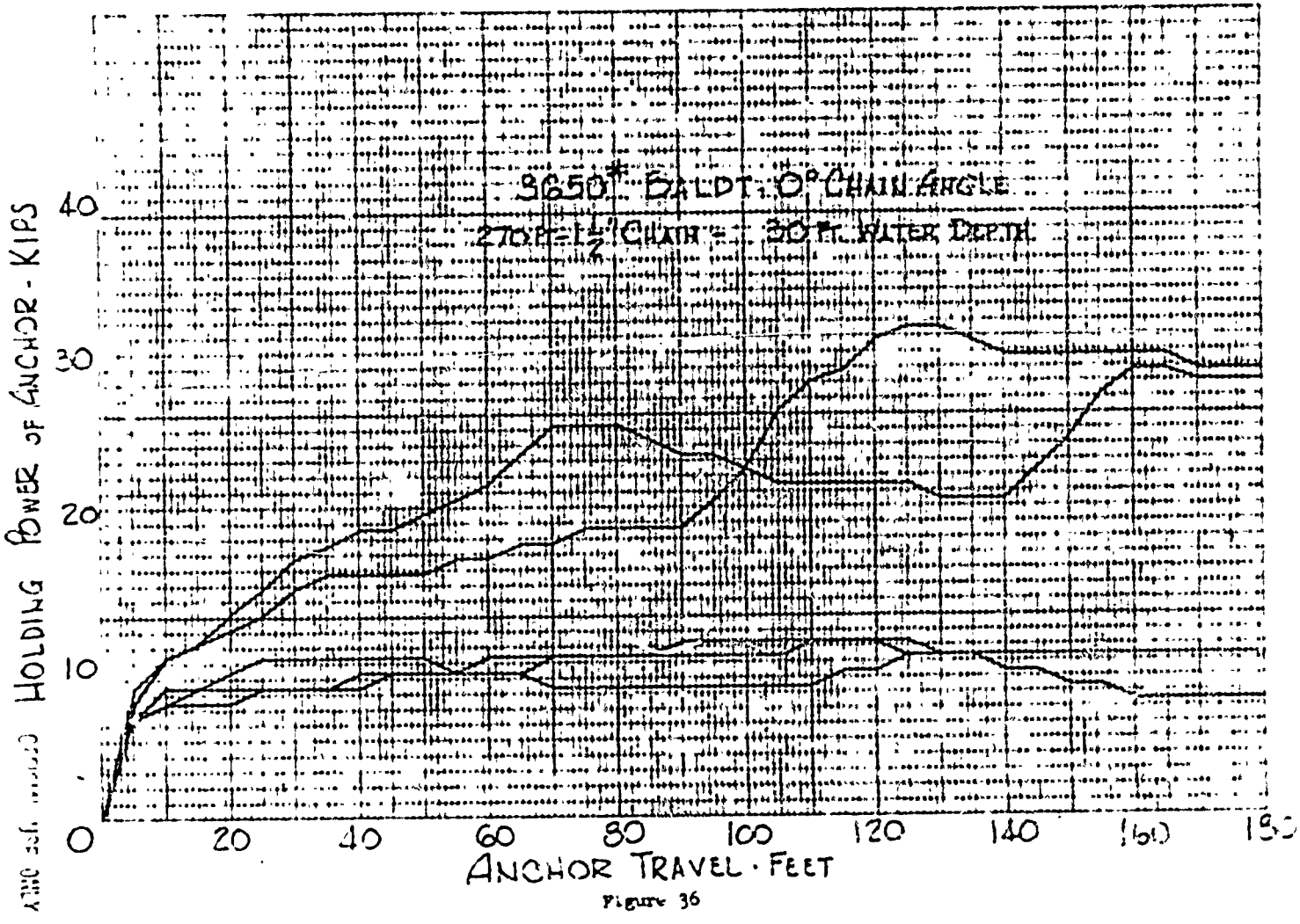

9650# DALDT, 0° CHAIN ANGLE
270 FT = 1½" CHAIN = 30 FT. WATER DEPTH
HOLDING POWER OF ANCHOR - KIPS
0
10
20
30
40
20
40
60
80
100
120
140
160
ANCHOR TRAVEL - FEET

Figure 36

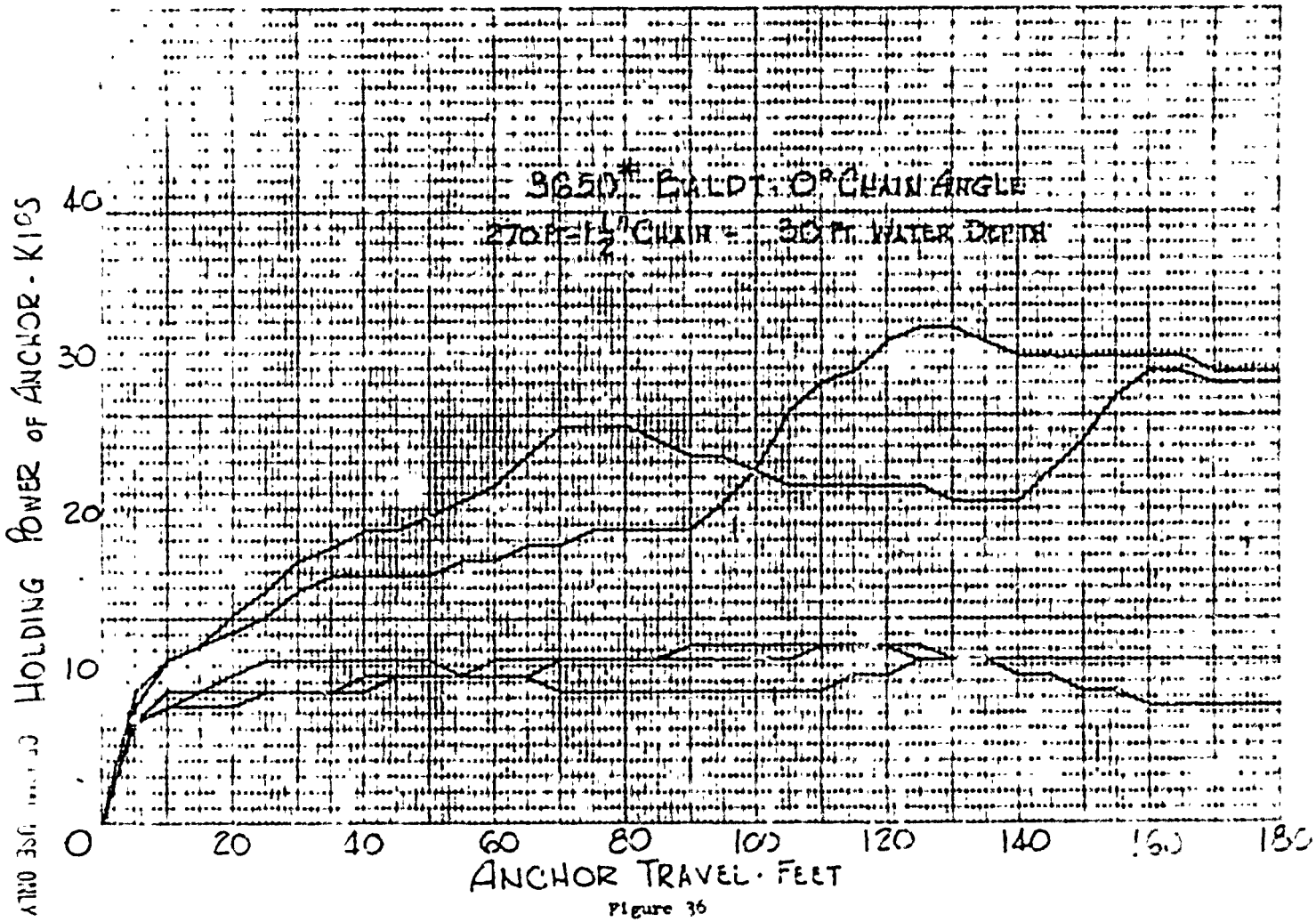

3650# BALDT: 0° CHAIN ANGLE
270 PT = 1½" CHAIN = 30 FT. WATER DEPTH
HOLDING POWER OF ANCHOR - KIPS
0
10
20
30
40
20
40
60
80
100
120
140
160
180
ANCHOR TRAVEL - FEET

Figure 36

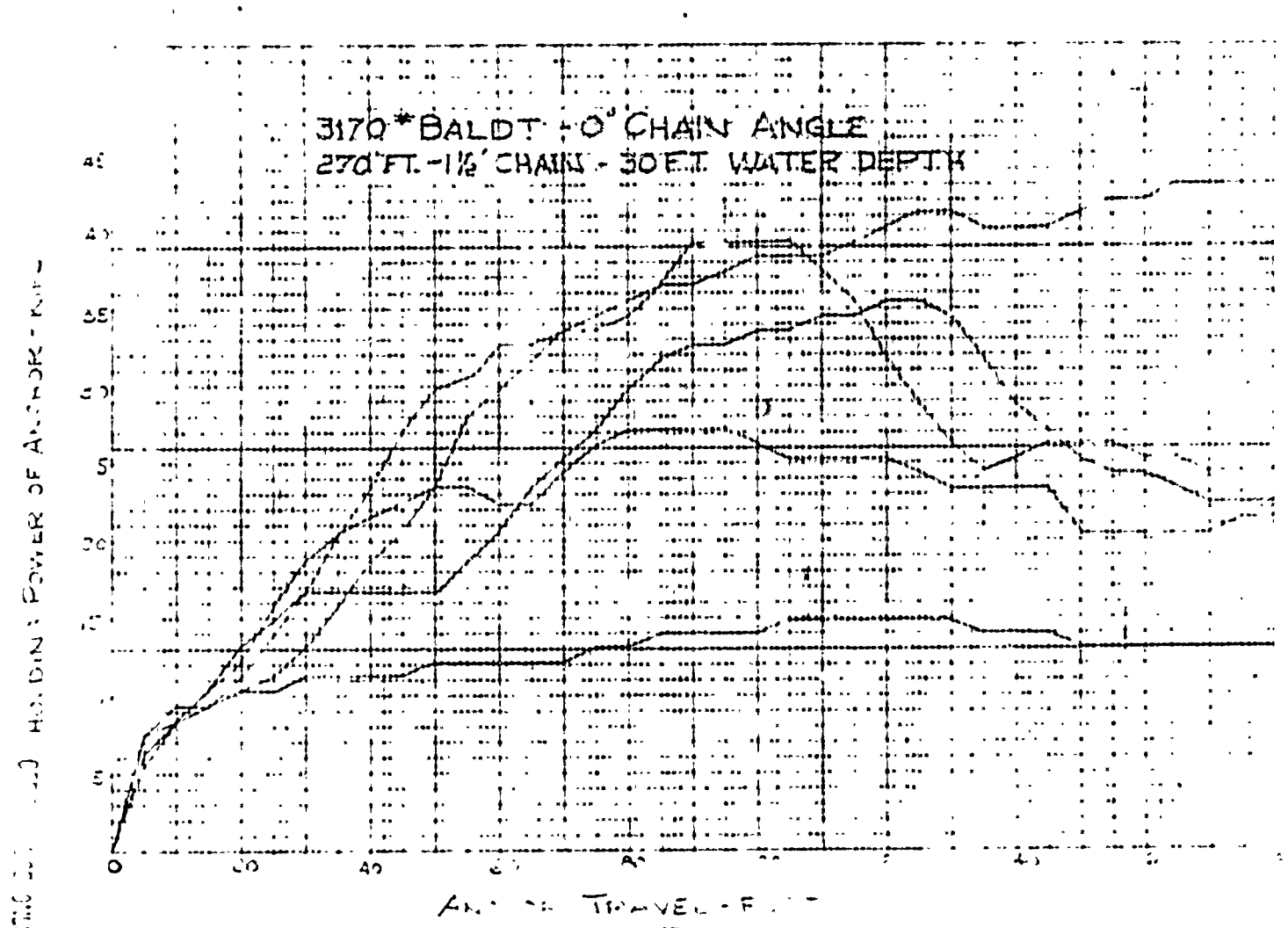


Figure 37

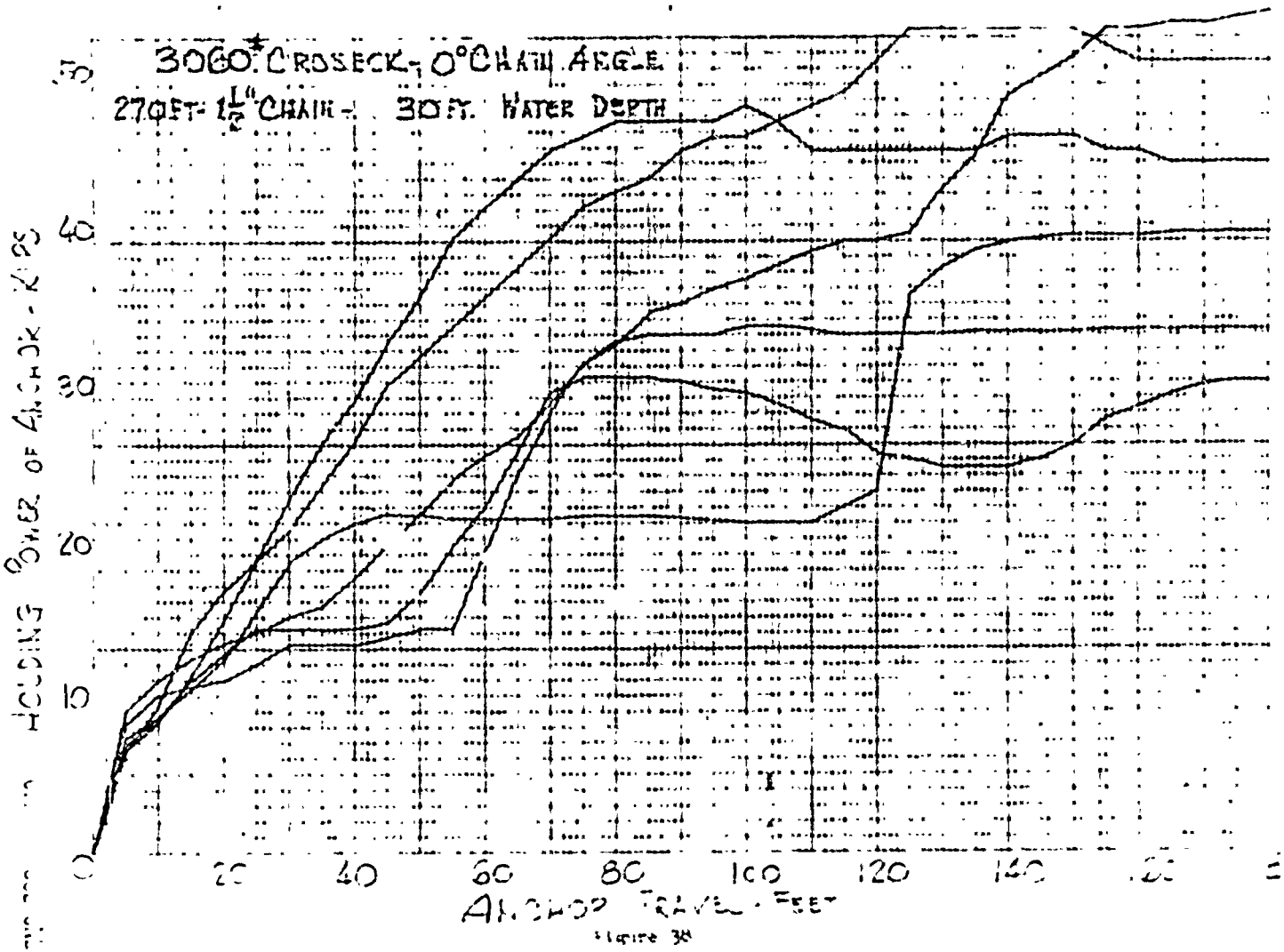

3060 CROSECK - 0° CHAIN ANGLE
270 FT - 1½" CHAIN - 30 FT. WATER DEPTH
HOLDING POWER OF ANCHOR - KIPS
0
5
10
20
40
60
80
100
120
ANCHOR TRAVEL - FEET

Figure 38

2000 lb. LWT-D5H
90 ft. 1¼ inch chain
HOLDING POWER OF ANCHORS K.P.S
0
10
20
30
10
20
30
40
50
60
ANCHOR TRAVEL-FEET

Figure 39

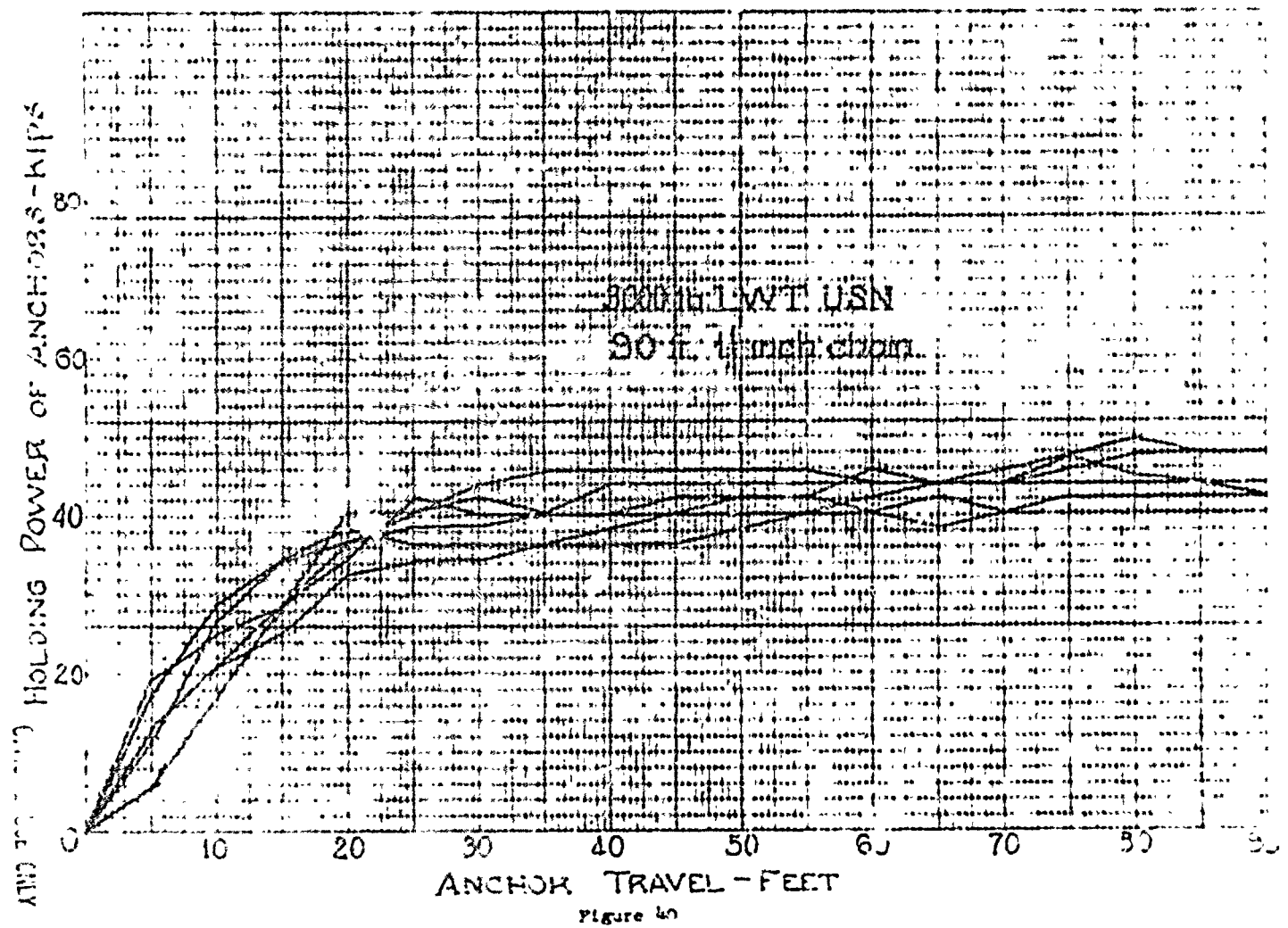

HOLDING POWER OF ANCHORS - KIPS
80
60
40
20
0
10
20
30
40
50
70
ANCHOR TRAVEL - FEET

Figure 40

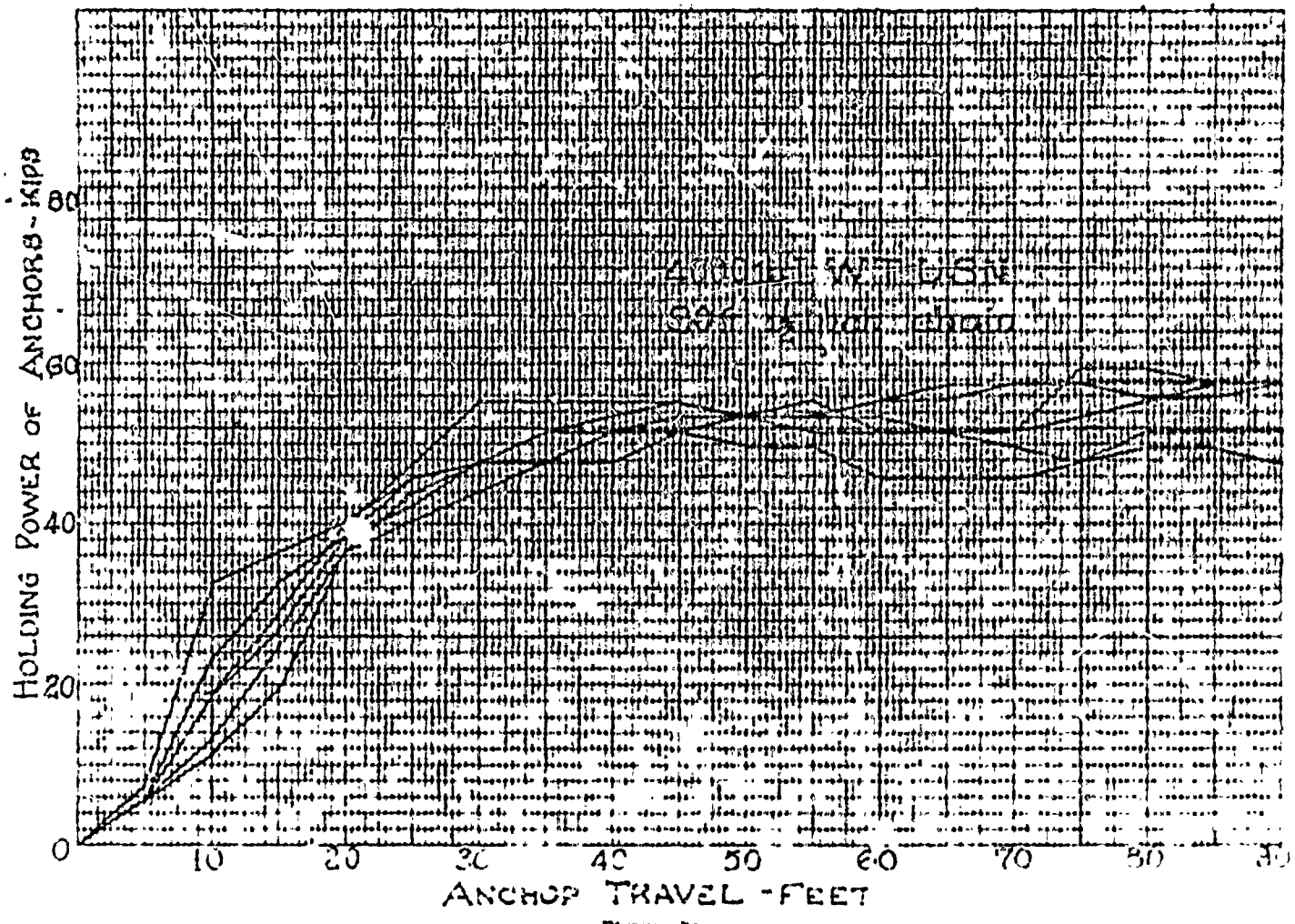


Figure 81

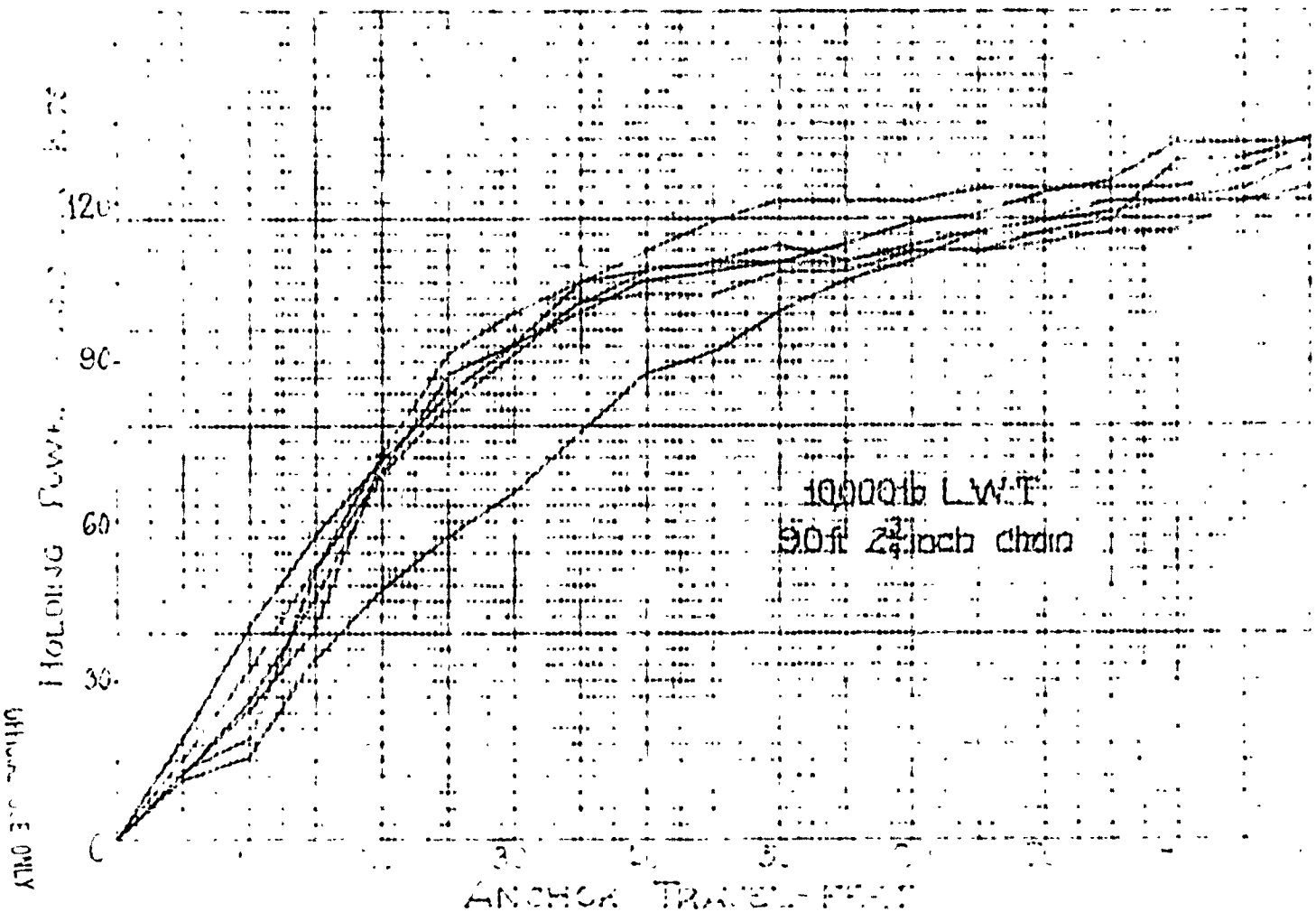

120
90
60
30
0
10000lb L.W.T.
90ft 2 3/4 inch chain
ANCHOR TRAVEL - FEET

Figure 12

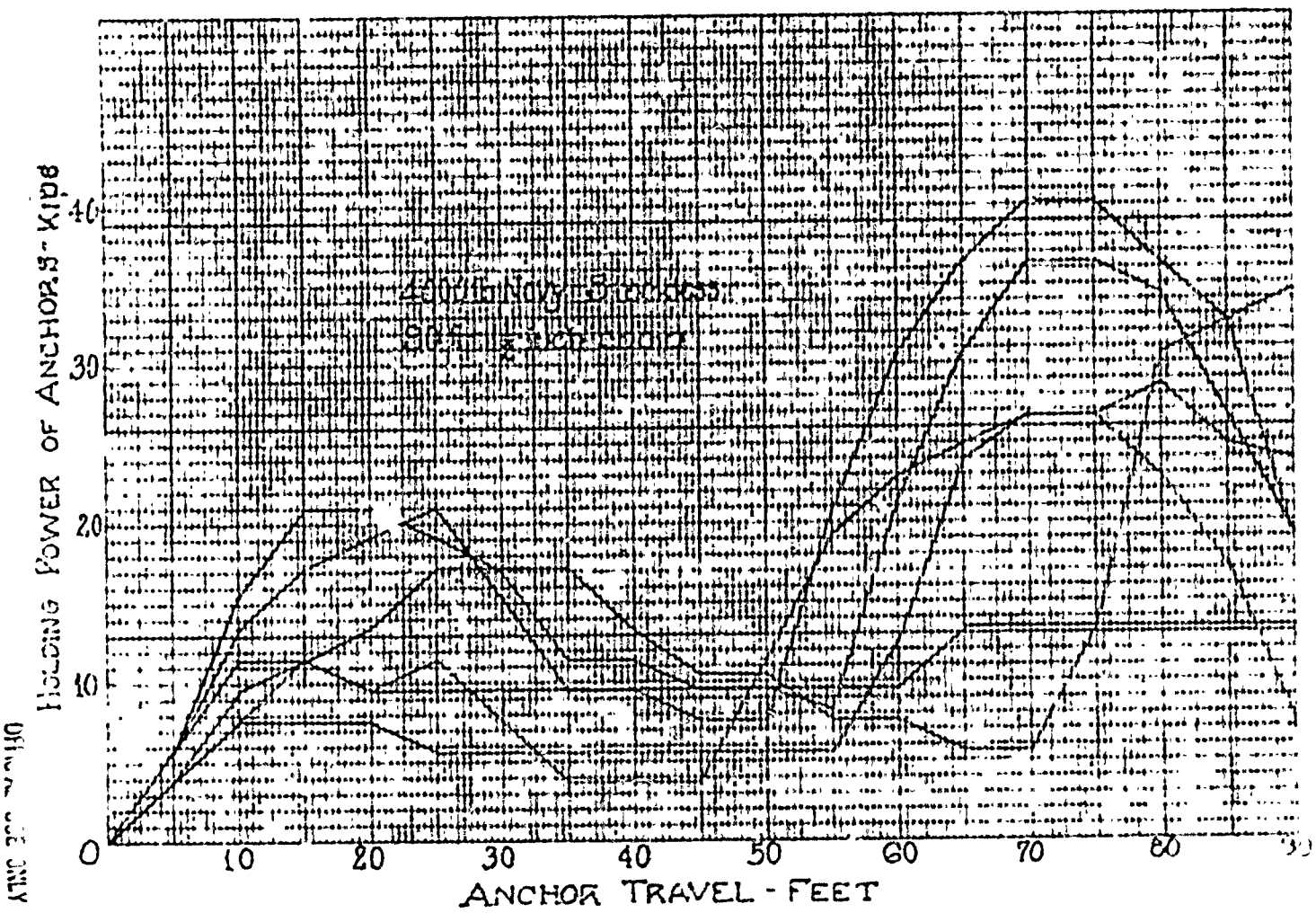

HOLDING POWER OF ANCHORS - KIPS
0
10
20
30
40
50
60
70
80
ANCHOR TRAVEL - FEET

Figure 53

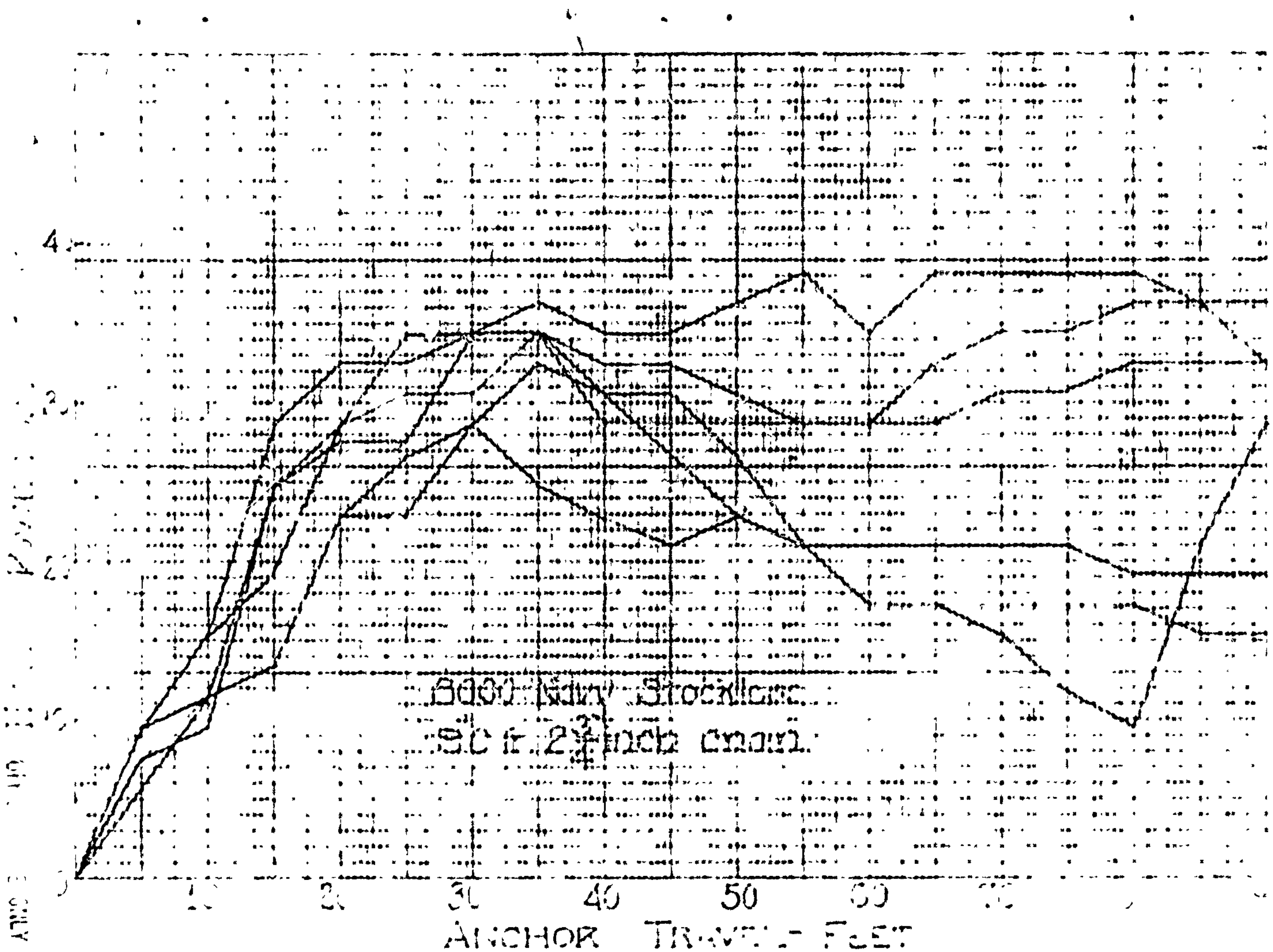


Figure 14

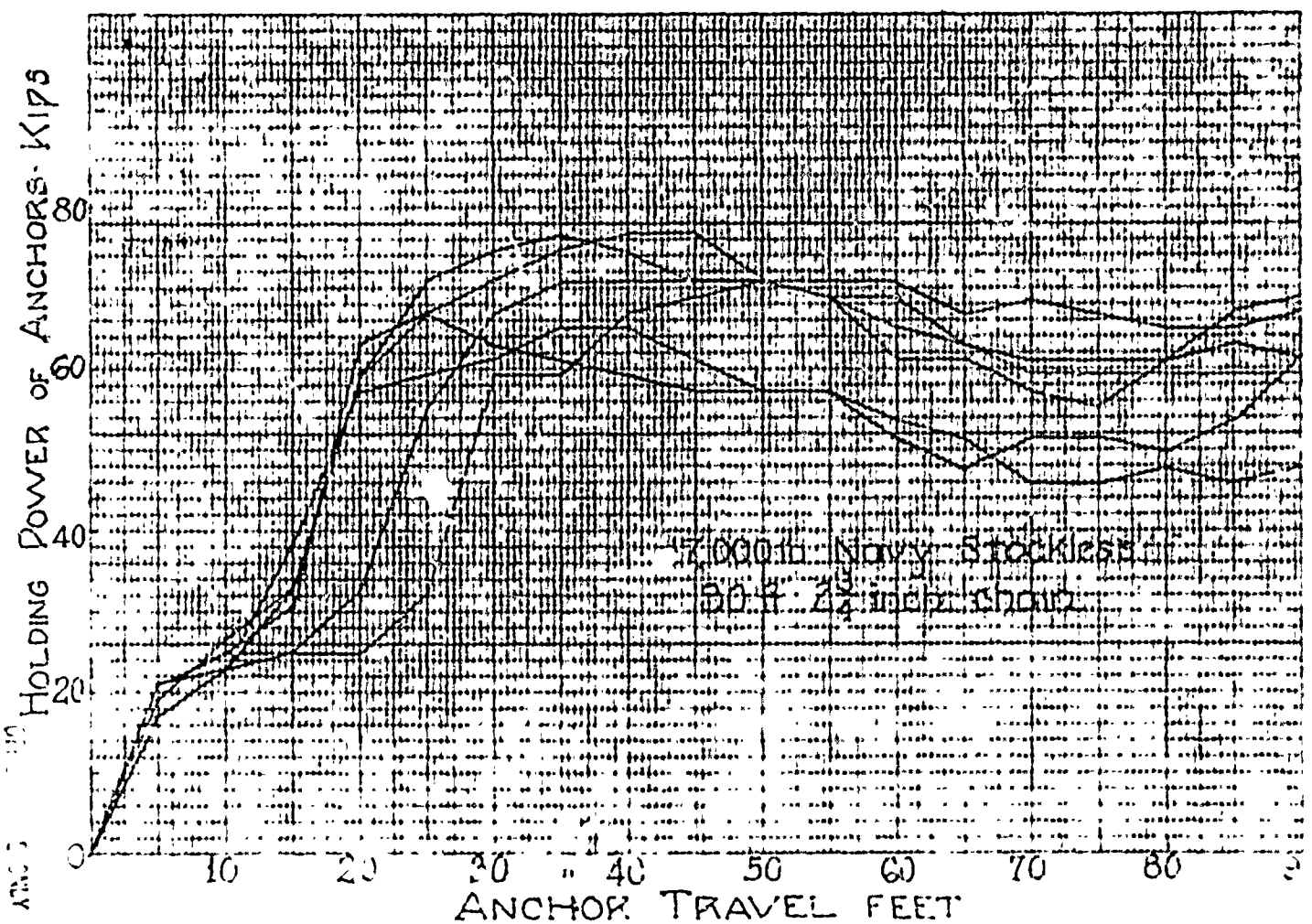

HOLDING POWER OF ANCHORS - KIPS
0
20
40
60
80
10
20
30
40
50
60
70
80
ANCHOR TRAVEL FEET
17,000 lb. Navy Stockless
90 ft. 2¼ inch chain

Figure 45

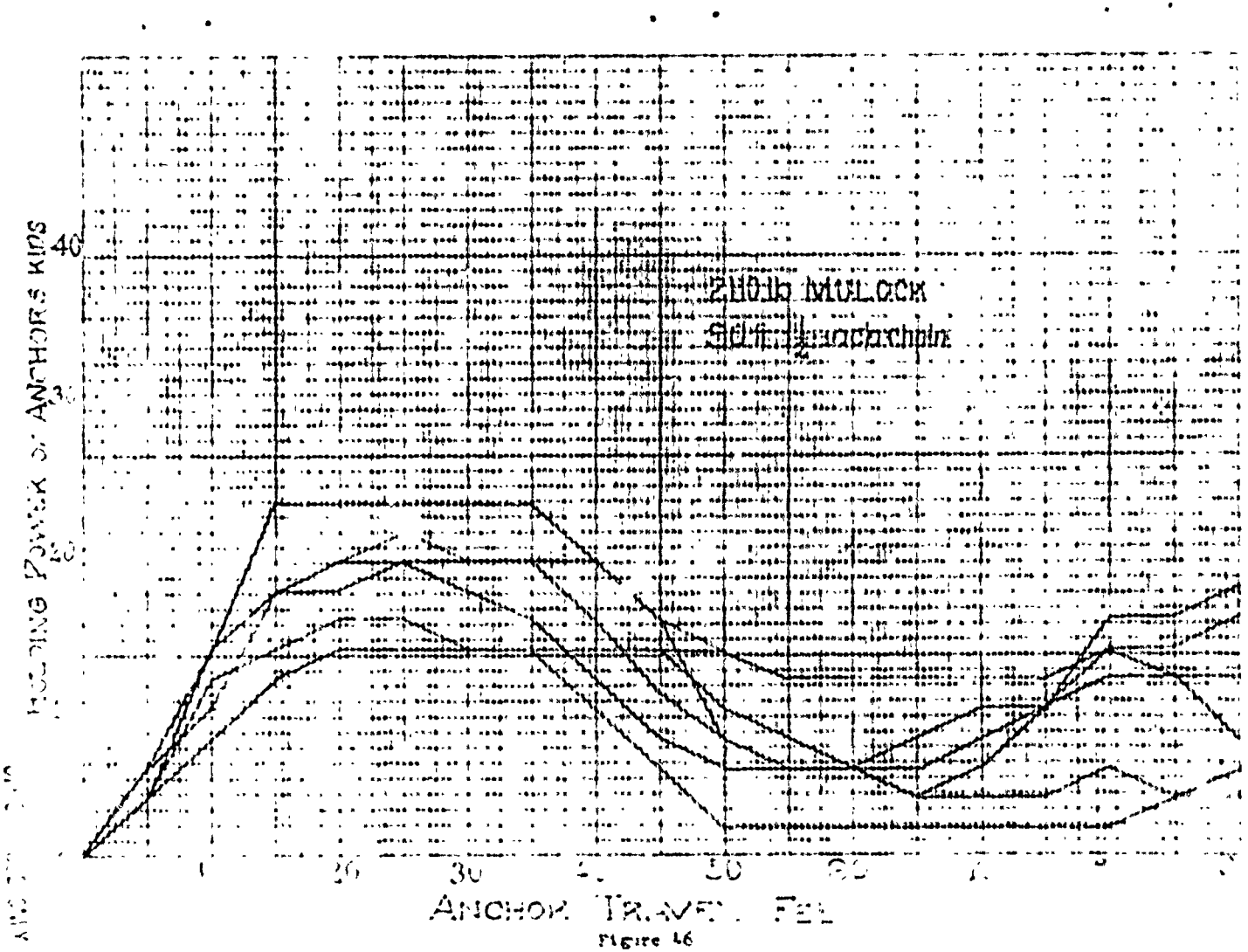


Figure 46

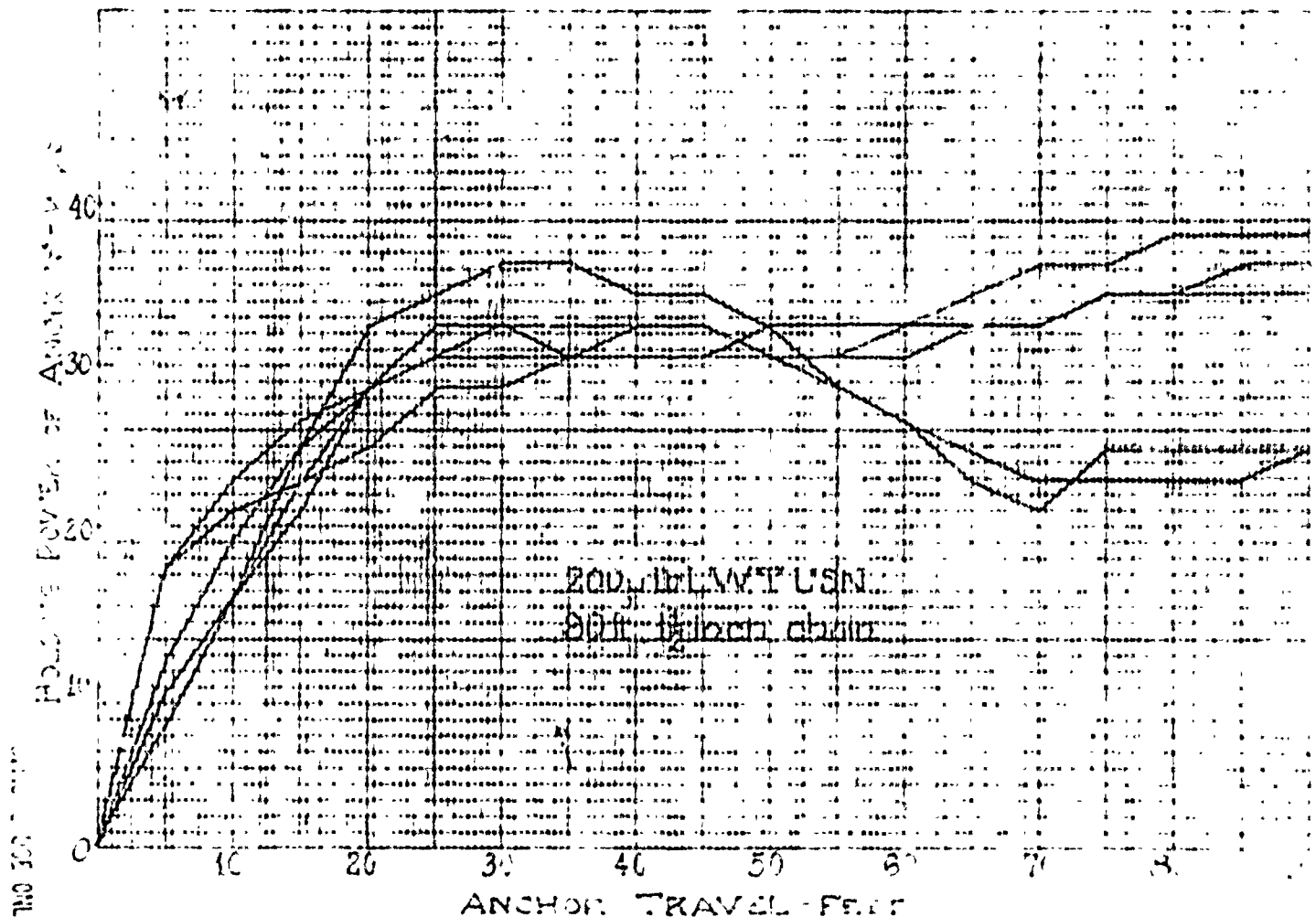


Figure 47

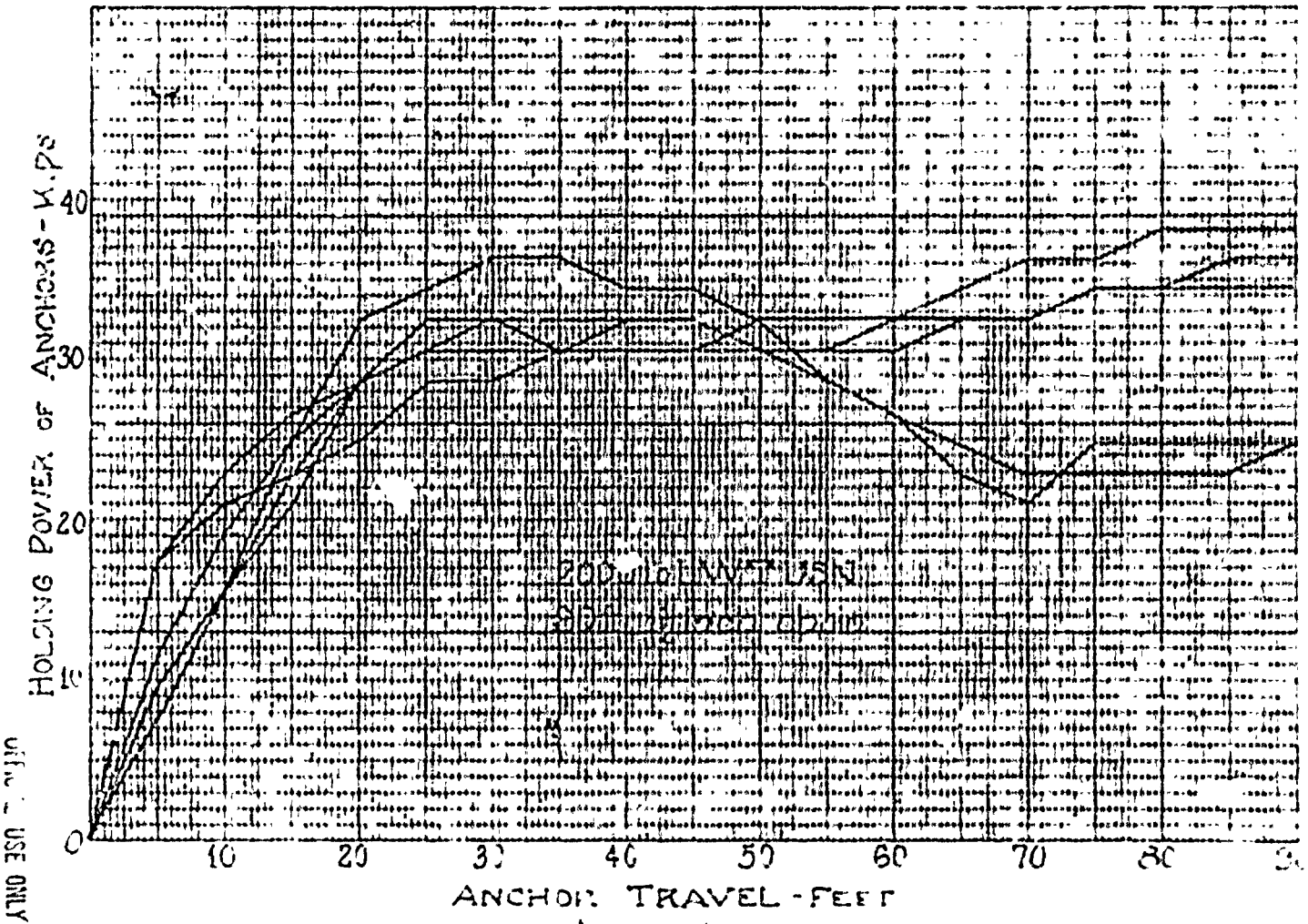

HOLDING POWER OF ANCHORS - K.P.S
0
10
20
30
40
10
20
30
40
50
60
70
ANCHOR TRAVEL - FEET

Figure 47

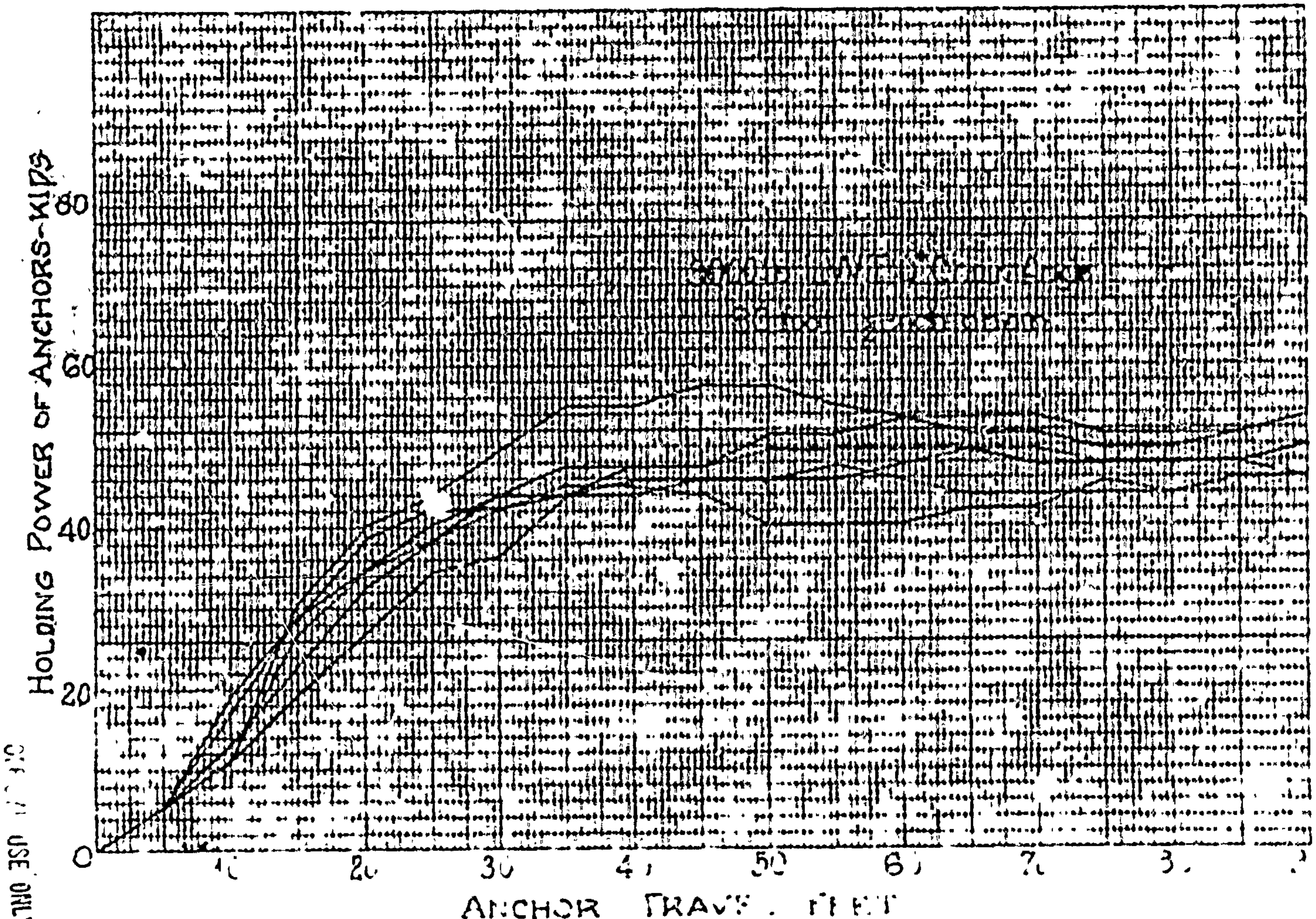


Figure 48

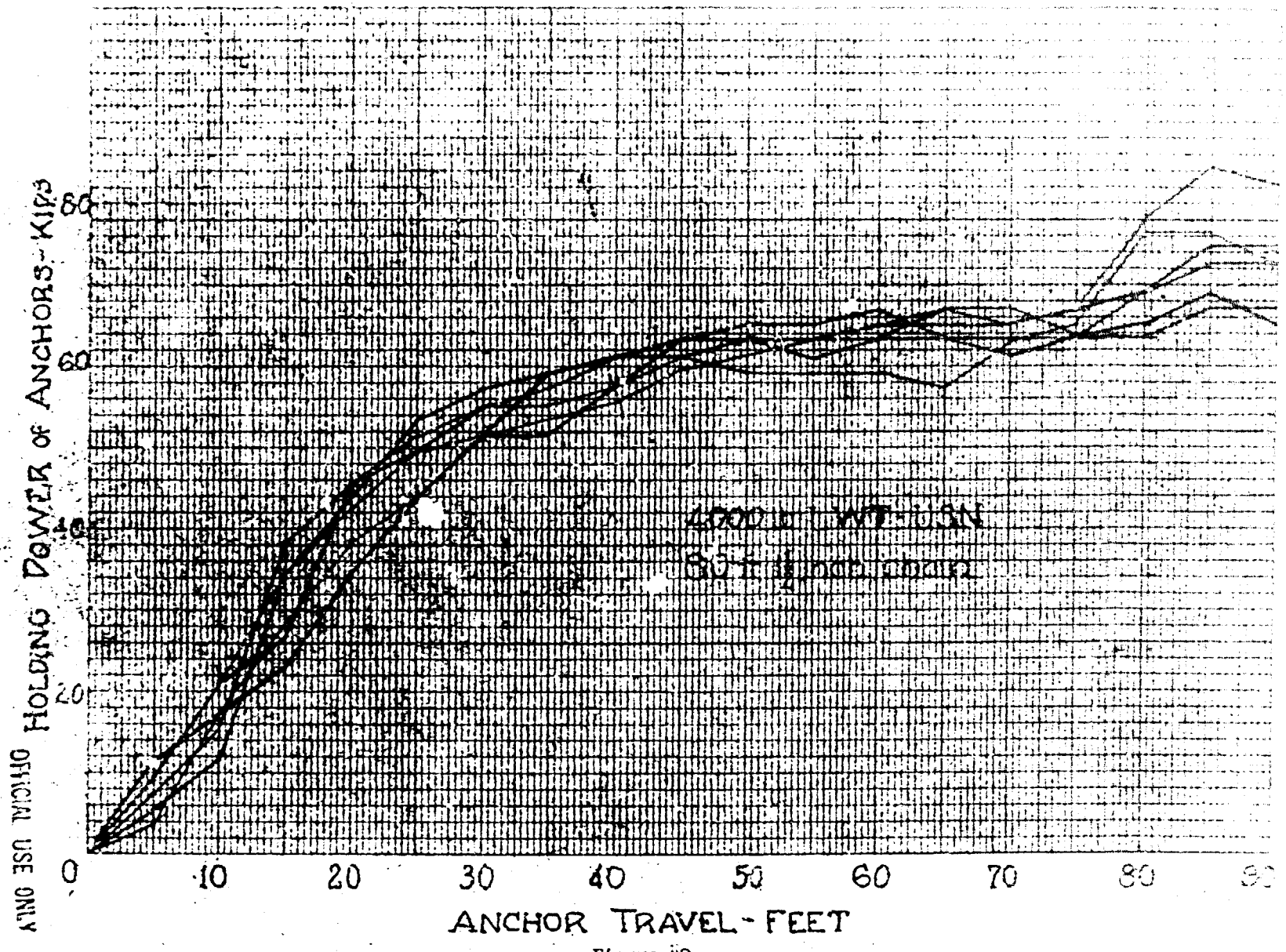

HOLDING POWER of ANCHORS - KIPS
0
20
40
60
80
10
20
30
40
50
60
70
ANCHOR TRAVEL - FEET
4000 lb WT USN
85 ft wood sloop

Figure 49

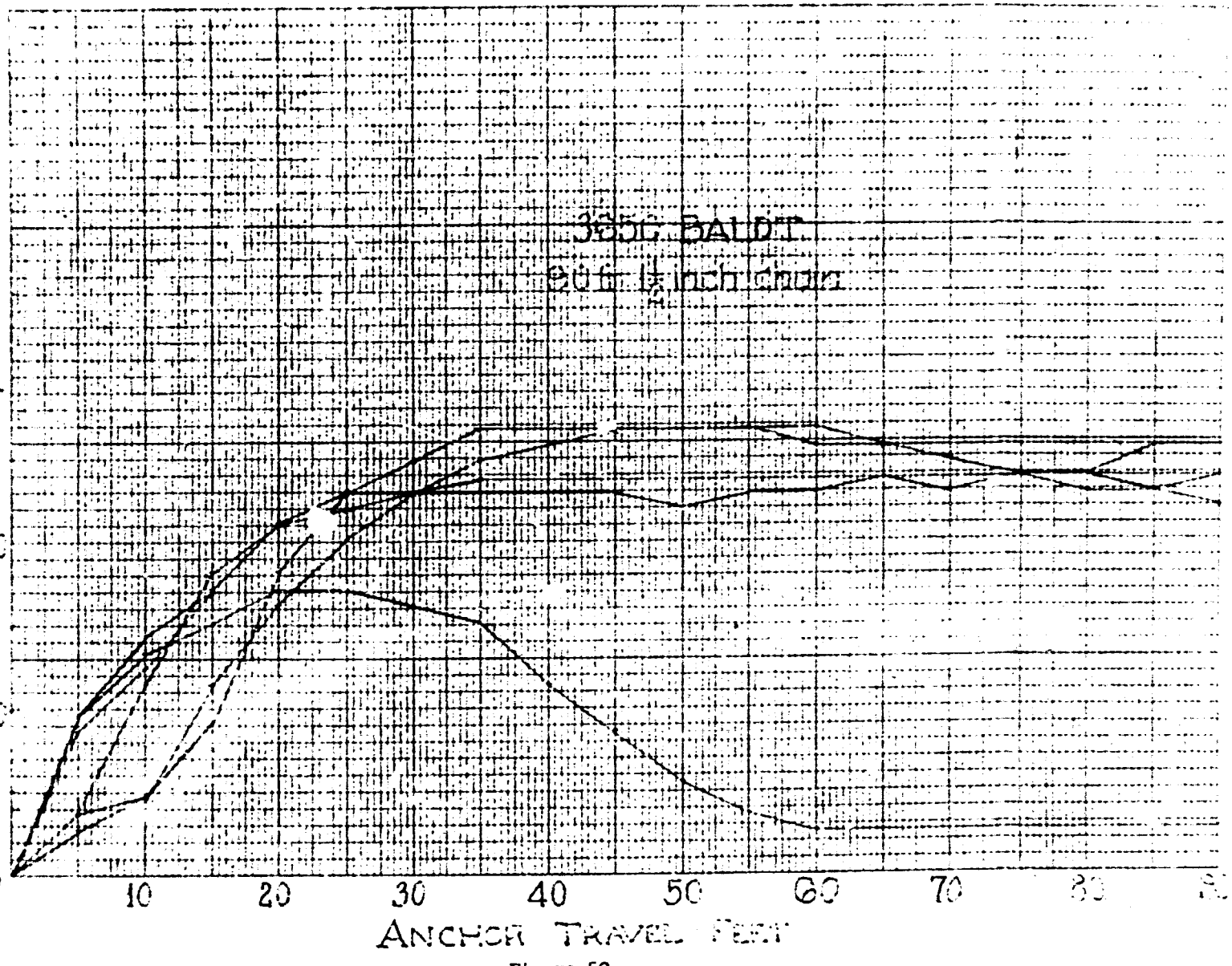


Figure 50

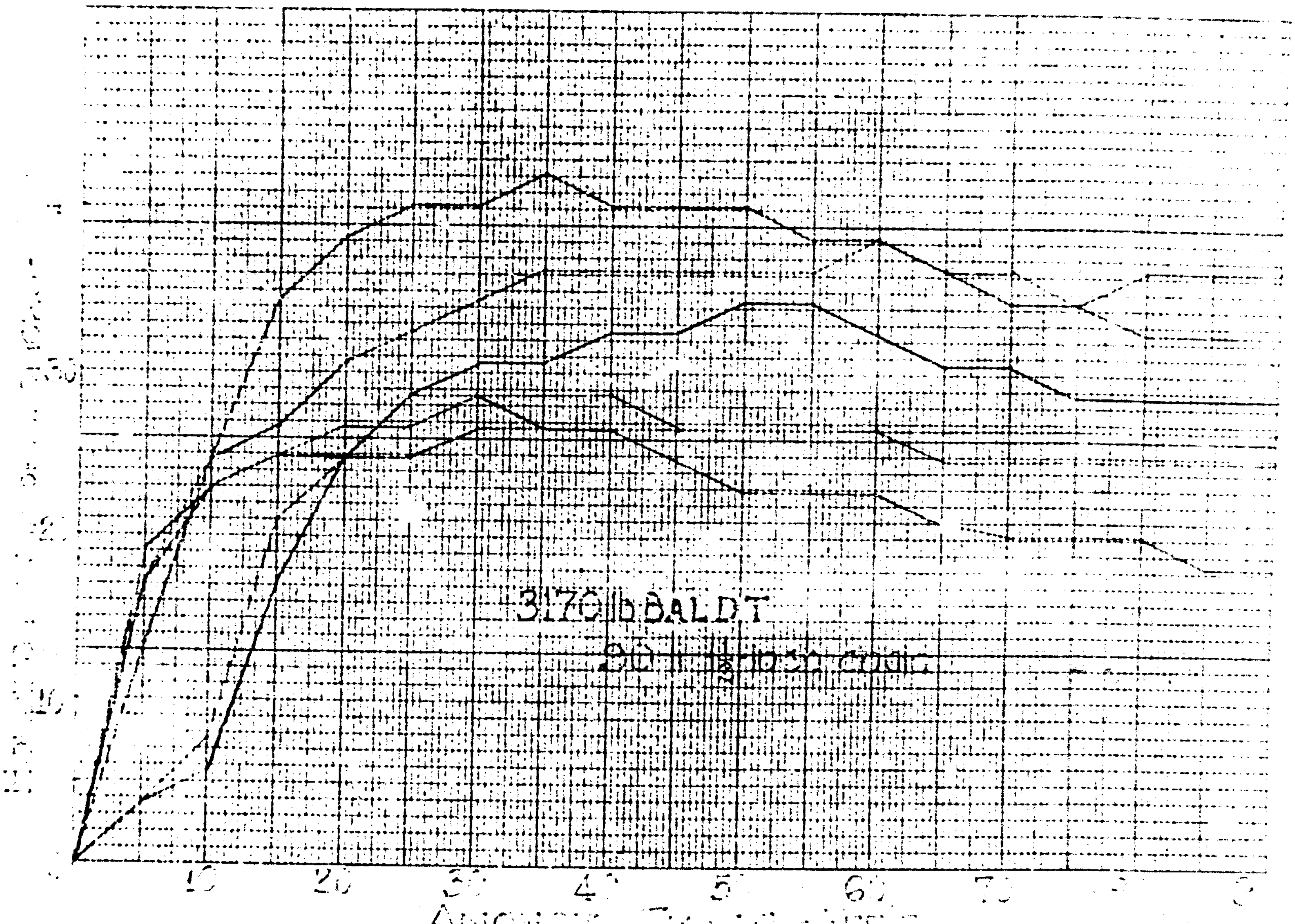


Figure 51

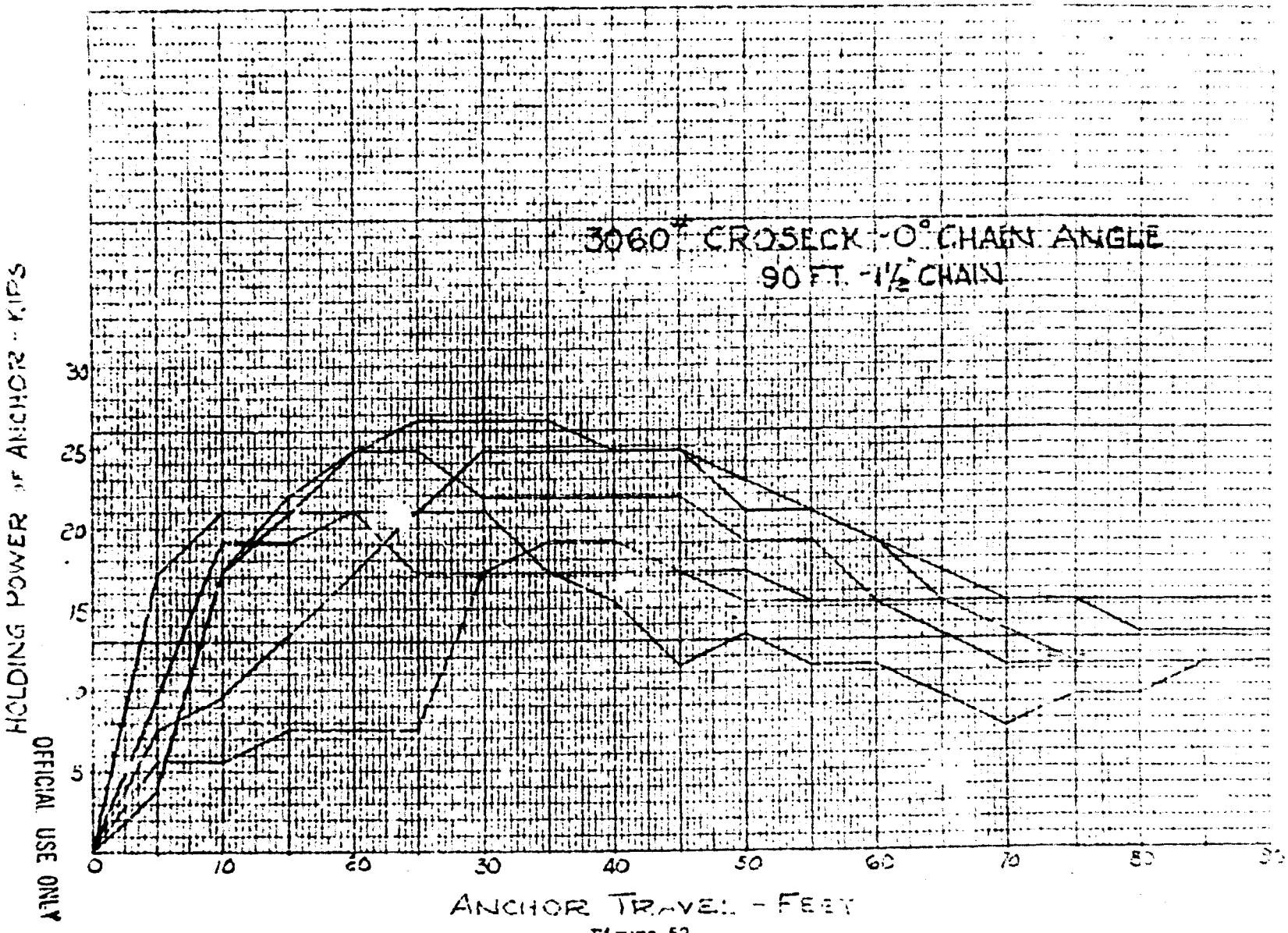

3060# CROSECK -0° CHAIN ANGLE
90 FT. - 1½" CHAIN
HOLDING POWER OF ANCHOR - KIPS
OFFICIAL USE ONLY
30
25
20
15
10
5
0
10
20
30
40
50
60
70
80
ANCHOR TRAVEL - FEET

Figure 52